THE MONTANA RENEWABLE ENERGY HANDBOOK

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geothermal

MONTANA DEPARTMENT OF NATURAL RESOURCES & CONSERVATION
DNRC
ENERGY DIVISION
November 1980

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THE MONTANA RENEWABLE ENERGY HANDBOOK

Prepared by
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November 1980

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Harold Jacobsen bermed the north side of his house near Stevensville to prevent heat loss caused by northern Arctic winds.

This solar system provides about 50% of the hot water requirements for the Barbara Clowers residence in Great Falls.

Dennis Howard installed a 160 square foot free standing air collector with rock bed storage to help heat his home in Glendive.

Richard Sheridan of Missoula has installed these insulating shelters to retain heat provided by his solar system.

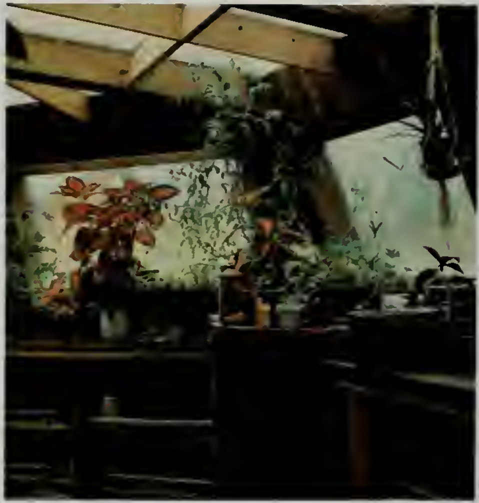
A novel approach to solar heating, these free standing units heat Dr. Sheridan's home in Pattee Canyon in Missoula.

Solar air collectors are mounted vertically on the south wall on the Great Falls Savings and Loan building in Conrad.

Larry Truchot's new house in Great Falls has a roof of 1,000 square feet of flat plate water collector with a water to air heat exchanger coupled to a forced air furnace.

Renewable energy systems adorn Dick Dill's home in the Bitterroot Valley. Water collectors are mounted on the workshop roof and air collectors are positioned on the south wall. A solar greenhouse joins the geodesic home with the workshop. Wood stoves provide additional heat in the dome as well as in the workshop.

These air collectors provide most of the space heat required by this home in Glendive built by Mike Stoltz.



Plants do extremely well in John Fisher's spacious greenhouse at the Jocko Hollow Campground near Arlee.

This cabin near Red Lodge demonstrates the harmony between solar heating and rustic design.

Bruce McCallum of Chester built this low cost attached solar greenhouse to provide a year round growing space and supplemented space heating.

A drum wall consisting of 50 gallon drums filled with water and painted black collect and radiate heat into a cabin at Jocko Hollow campground. The panels in the foreground reflect additional light and close shut at night to prevent heat loss to the night air.

During the summer, trees shade south facing windows which provide direct gain, space heating to Peter Rechtfertig's Billings home.

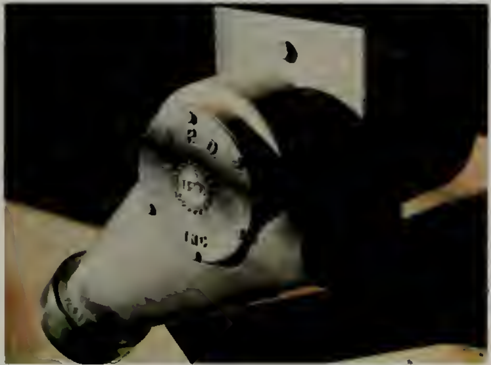
Joe Frechette employed innovative construction to build this direct gain solar home at Darby.

Insulating shutters in Rechtfertig's home lower at night to keep in the heat gained during the day.

This greenhouse in Bozeman designed and built by Peter Gobby features 320 square feet of double insulated glass, water storage and an insulated basement.

Reynold Zusman of Mosby poses with a wind turbine of his own design which combines a savonius rotor with a cyclo turbine.

The turbine is connected to a 32v D.C. generator (the red unit).

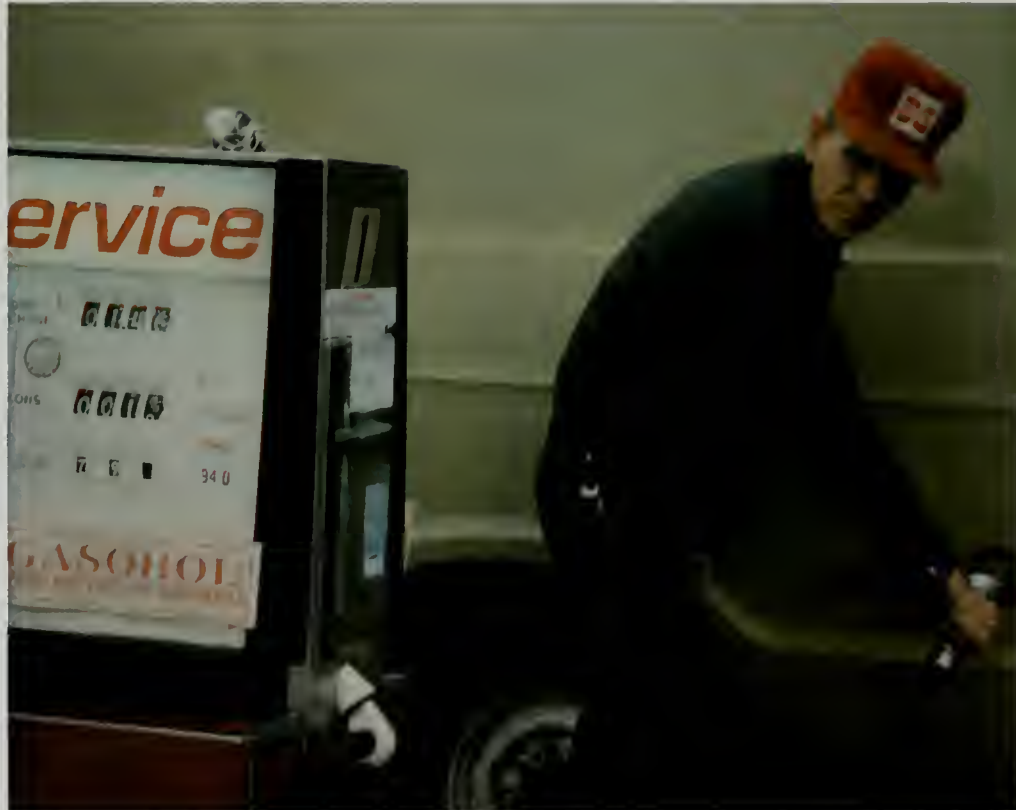


Arnie Oschmann installed this 4'' impulse turbine near his home.

The direct current is either stored in regular car batteries or it is converted to alternating current by the inverter to the left of the batteries for residential use.

This shack houses Oschmann's hydro system.

These two old pelton wheels are to be rebuilt.



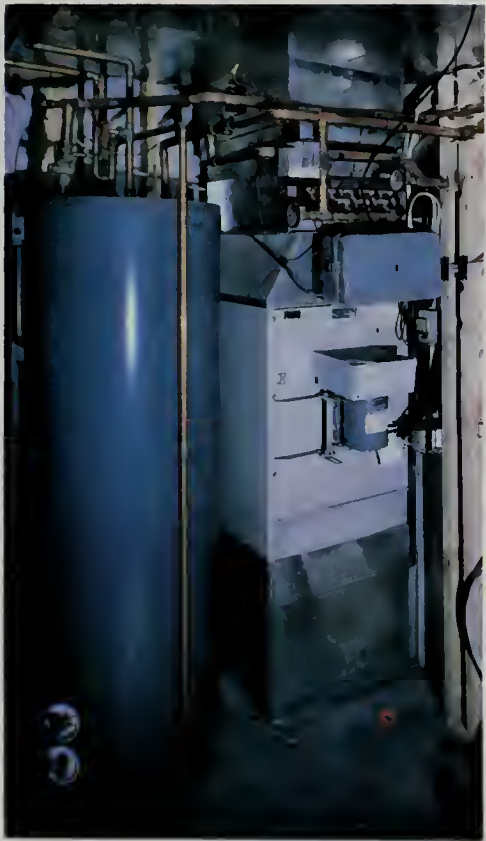
Gary Coolidge of Burt Gibson's Cenex in Lewistown fills a customer's gas tank with gasohol.

Doug Polette's wood fired boiler boasts a 1,500 gallon storage tank to heat his Bozeman residence.

The firebox and heat exchanger of Polette's boiler provide the mechanism for hot water heat.

Dick Dill of Stevensville designed and fabricated this air tight wood stove for his shop. The stove draws outside combustion air for complete combustion and also heats water for the domestic hot water supply.

The Hippert wood furnaces are manufactured in Whitehall.



Heat exchangers in the blue hot water tank and the forced air furnace to the right of the water tank extract heat from the geothermal spring water to provide domestic hot water and space heat.

Conventional as Frank Gruber's house outside of Helena may appear it is heated by a geothermal spring.

INTRODUCTION

The **Montana Renewable Energy Handbook** is designed to meet Montanans' need for reliable information on the use of renewable energy systems. The information should be useful not only to those with little knowledge about renewable energy but also to those individuals with experience in the theory and application of renewable energy systems.

Discussed in the **Montana Renewable Energy Handbook** are active and passive solar systems, small scale wind energy conversion systems, small scale water systems, biomass and wood energy systems, and geothermal systems. Each of these renewable energy systems is explored as it relates to Montana's particular needs and resources, the basic technology involved is explained, and cost comparisons and basic problems in utilization are presented. A chapter on conservation precedes the discussion of renewable energy systems because conservation measures are necessary to insure the efficient use of all kinds of energy.

"The tragedy of modern man is that he seriously believes that heat comes from the stove and the food from the corner store."

Aldo Leopold

"We have been moving away from a world that runs itself...to one that requires constant tinkering that is malignant in that each act of repair generates a need for further repairs to avert problems generated at compound interest."

George Woodell

A number of appendices are included in the **Handbook**. The appendices include summaries of technical information, a directory of Montana and out of state renewable energy organizations, a glossary of technical terms, and tables of the potential environmental impact of renewable energy systems.*

A bibliography of books and periodicals at the end of each chapter highlights four or five important sources and lists several other titles. Throughout the **Handbook** specific renewable energy systems in operation in Montana are highlighted and explained in text and photographs.

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*A directory of manufacturers, distributors and designers of renewable energy systems as well as a directory of projects funded by the Alternative Renewable Energy Grants Program are available under separate cover from the Department of Natural Resources and Conservation.

Special emphasis in the **Handbook** is given to active and passive solar systems, small-scale wind energy conversion systems and wood systems. These systems have already reached a commercial stage of development and they are currently the most economically feasible renewable energy systems for use by Montanans. Emphasis is also given to the application of renewable energy systems to individual dwellings—the use of renewable energy by industry or communities is not discussed

The **Handbook** is not a guide to the actual construction of renewable energy systems. Rather, it is intended to lay the groundwork, to enable the reader to ask the proper questions and make the necessary decisions preliminary to actual construction.

The application of renewable energy sources is attractive in many ways. In its 1978 report, **Solar Energy: Progress and Promise**, the President's Council on Environmental Quality cites the following advantages to solar energy use:

- *It is abundant and renewable. Huge amounts of solar energy are potentially usable. Solar energy flows through the earth's natural system at a rate about 10,000 times greater than all energy from the world's fossil- and nuclear-powered machines. In principle, with an average collection efficiency of only 15 percent — achievable with present technologies — all of our current energy needs could be met by using roughly 1 percent of our land area.*

- *It is universally available and not as vulnerable to large-scale human intervention whether by strikes, embargoes, fuel price boosts, or anti-trust agreements.*

- *Its effects on the economy and employment are highly beneficial. Widespread adoption of the various solar technologies would create an enormous number of jobs of many types — from welders to plumbers, from sheet-metal workers to electrical engineers, from architects to carpenters. Several studies as well as some new preliminary data to be published shortly, indicate that capital investment in solar heating or wind power systems will generate between two and five times as many jobs as the same expenditure for central station electric power plants. Similar conclusions follow from a recent analysis of the employment implications of solar energy development in California. The study estimated that widespread use of solar space and water heating systems to help meet the state's energy needs alone could generate more than 375,000 jobs per year during the coming decade, cutting California's unemployment rate nearly in half.*

- *Its environmental impacts are minimal. With careful design and operation, solar energy technologies can be expected to have far fewer and far smaller detrimental effects than conventional sources providing equivalent amounts of energy. Unlike coal, solar poses little risk to climate and creates little direct air pollution; unlike nuclear, it poses no radioactive hazards and no risk of nuclear weapons proliferation. The principal impacts of solar energy are on land use, and even in that respect it may compare favorably with alternative sources of energy when the entire cycle of the energy system is considered.*

"We should not tackle vast problems with half-vast concepts."

Preston Cloud, Jr.

In spite of its comparative advantages, renewable energy sources have not yet been significantly implemented. To a certain degree, existing institutional arrangements have prevented wide-spread implementation. The barriers to the application of renewable energy sources to meet today's energy needs can be resolved by further work on both a technical and policy level. The eventual implementation of renewable energy systems will pose environmental and social problems and these must be recognized and evaluated.

"The object of man's game with nature is not to win but to keep on playing."

The **Montana Renewable Energy Handbook** is based on the most current information available, but given the rapid advances in renewable energy technology, some of the information in this **Handbook** probably will become dated. However, the basic principles governing the utilization of renewable energy sources, which are discussed throughout the **Handbook**, will remain applicable

It is hoped that the **Montana Renewable Energy Handbook** will assist the many Montanans who are interested in tapping renewable energy sources.

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Other Homes & Garbage — Designs for Self-Sufficient Living, by Leckie, Masters, Whitehouse and Young, 1975. An introduction to basic energy-conserving design principles, wind-electric generation, solar heating, waste-handling, water supply and agriculture, all applied to the home scale. It contains many graphics and charts. $9.95 from Sierra Club Books, 530 Bush Street, San Francisco, CA 94108.

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Alternative Sources of Energy is a general publication on renewable energy Published monthly from ASE, Route 1, Box 90-A, Milaca, MN 56353

Elements contains news on resources, energy and agriculture on an international scale. Published monthly from 1520 New Hamshire Avenue, N.W., Washington, D.C. 20036.

Energy and Alternatives is concerned with the transition to renewable energy. Published quarterly from Solar Utilities Negotiations, P.O Box 681, Salem, OR 97308.

Environment Magazine has in-depth articles, some on energy. Published monthly, from 560 Trinity Avenue, St. Louis, MO 63130.

High Country News has in-depth articles on renewable energy action in the Rocky Mountain states. Published bi-weeklyat $12/year from Box K, Lander, WY 82520.

CHAPTER I

Step I for Everyone: Conservation

During 1978, the Montana Energy Office compiled the results from energy audits of 10,030 homes in Montana. The audits revealed that 35 percent of these homes lose heat through poorly fitting windows, 54 percent have ill fitting doors, 28 percent require additional caulking and weatherstripping, 12½ percent have inadequate insulation, and 1½ percent have no insulation. If these 10,030 homes were properly weatherized, the estimated savings annually would be 320 billion BTU or 93,333,333 kilowatt hours.* The Department of Community Affairs (DCA) has assisted in the weatherization of 5900 low income homes. DCA estimates that conservation measures will save 200 billion BTU or about 58,479,533 kilowatt hours annually.

One million BTU saved through conservation is one million BTU available for future use. An effective conservation program throughout all energy consuming sectors in Montana could save an amount of energy equivalent to the output of a large-scale power plant. Also, it is cheaper to save energy than it is to produce new energy. In 1976, Bonneville Power Administration contracted with the consulting firm of Skidmore, Owings and Merrill to study the northwest regional potential for electric energy conservation. Skidmore, Owings and Merrill estimated that the cost of saving 1 million BTU was one-sixth the cost of producing 1 million BTU of new electricity.

Successful conservation means using less energy for everyday tasks. Conservation techniques must be understood and applied for a structure to be energy efficient—whether renewable energy or conventional fuel systems are used.

Discussed in this chapter are the principles of heat flow, and energy conservation technique for existing and new buildings, including earth shelter construction.

' "The modern economist is used to measuring the standard of living "By the amount of annual consumption assuming all the time that a man who consumes more is 'better off' than a man who consumes less. A Buddhist economist would consider this approach excessively irrational since consumption is simply a means to human well being. The aim should be to attain the maximum of well being with the minimum of consumption." '

E. F. Schumacher
"Buddhist Economics"

*To convert BTU to kilowatt hours, divide by 3412

Understanding Heat Flow

In cold weather, heat flows out of all structures, but the rate of flow is variable and controllable.

In a poorly insulated house, energy is wasted because heat flows rapidly out of the structure. Figures 1-1 and 1-2 illustrate the relation between heat flow and energy consumption and Figure 1-3 shows heat loss areas in a typical house.* Heat is lost from a structure in two ways: through its exterior surface by means of conduction, and through infiltration.

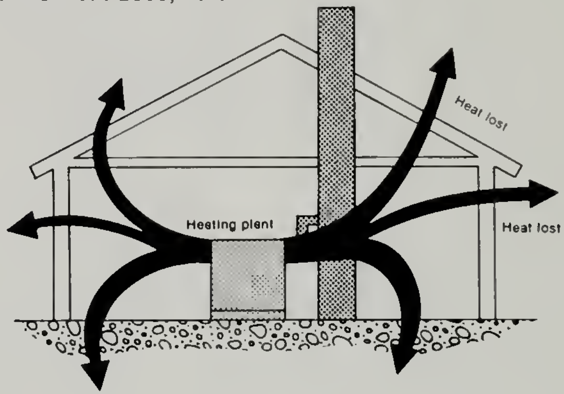
Conduction

Conduction is heat loss through building materials which comprise the exterior surfaces of a structure (walls, roofs, windows, basement, etc.). The rate of heat loss through the building materials depends on the size of the surface, the temperature difference between the two sides of the exposed area, and the type and thickness of materials used in the construction of the section. Some building materials are more resistant to heat loss than others. The more effective materials, those with a high resistance value (R value), are used in insulation.

When building sections are made of several materials, the resistance value of each material is added to obtain the total resistance value. To measure heat flow, U value is used. For an explanation of U value and a sample measurement of heat flow, see Appendix A, page 81.

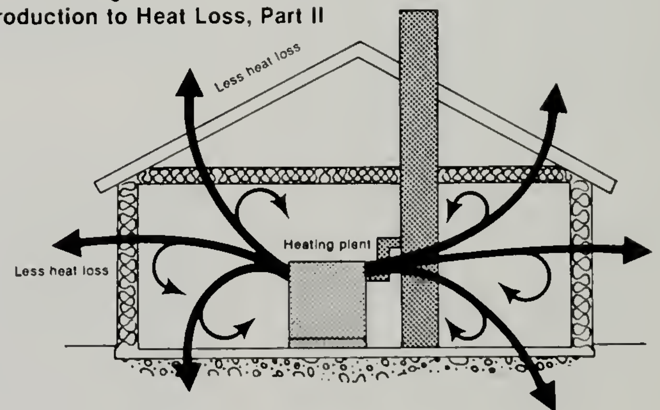
*To measure the amount of energy being wasted, the British Thermal Unit (BTU) is normally used. A BTU is the amount of heat it takes to raise the temperature of one pound of water by one degree Fahrenheit. One BTU is roughly equivalent to the amount of heat given off when a wooden match is burned completely. All fuel values or heat requirements may be expressed in BTUs. For example, one kilowatt hour of electricity is 3 412 BTU; one pound of wood burned completely will give off about 8 000 BTU (depending on its moisture content).

Figure 1-1.
Introduction to Heat Loss, Part I



If heat given off by the heating plant equals heat loss from the building, temperature inside remains constant.

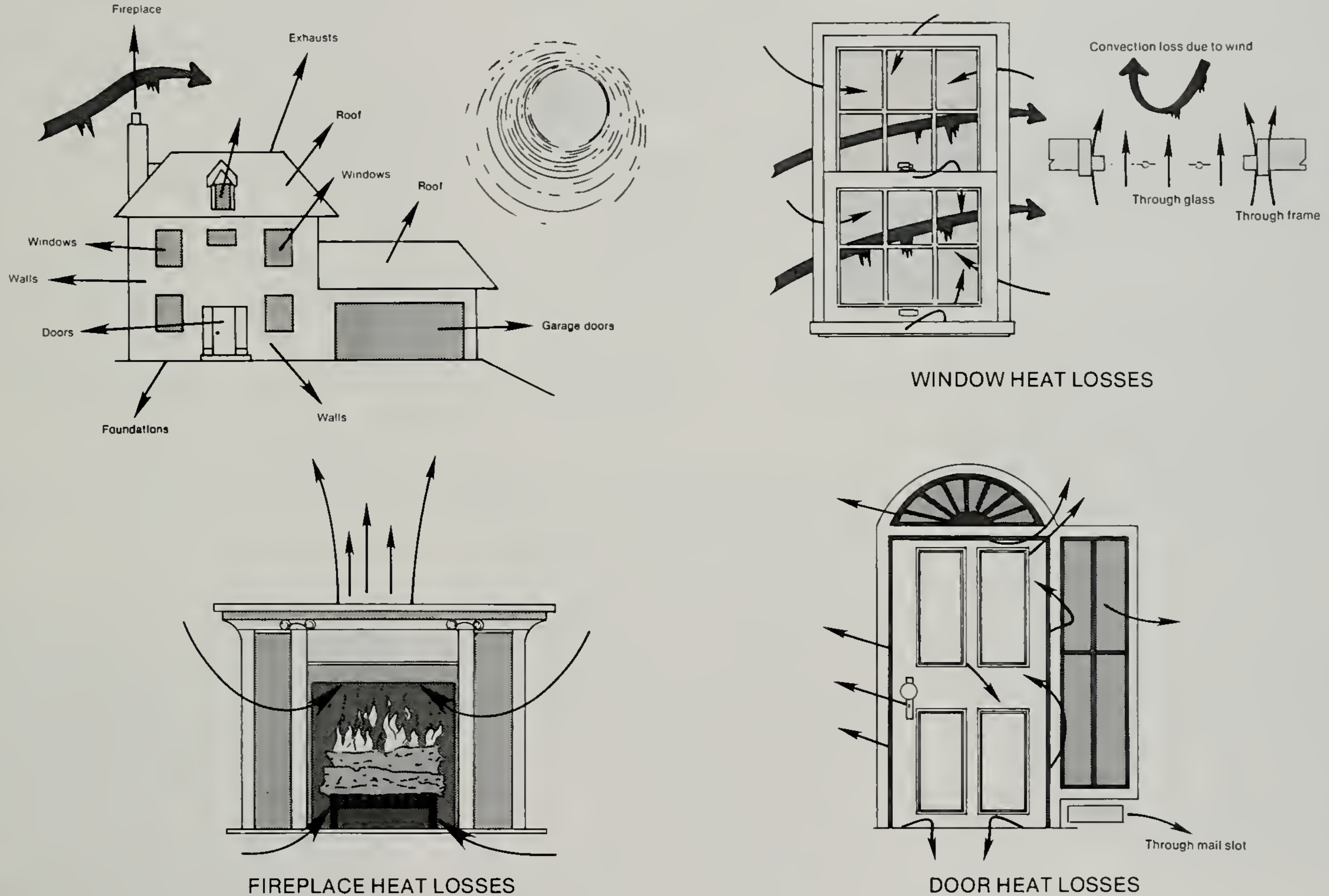
Figure 1-2.
Introduction to Heat Loss, Part II



Less heat escaping means less heat and less fuel needed to stay comfortable inside.

Source: **The Complete Energy-Saving Home Improvement Guide**, edited by James W. Morrison, Arco Publishing Company, Inc., New York, 1978

Figure 1-3.
Heat Loss Areas in Typical Houses



SOURCE: **Sun-Earth: How to Apply Free Energy Sources to Our Homes and Buildings**, Richard L. Crowther, A B Hirschfeld Press, Inc., Denver, Colorado, 1976

Infiltration

A building also loses heat through a process known as infiltration—the exhange of inside air with outside air. Infiltration occurs when there is a difference in air pressure between the inside and outside of a structure. This difference can be caused by wind, heat from a furnace or fireplace, or by temperature variations in the building. Exchange of air is necessary for ventilation, but most buildings have excessive exchange. In most houses the equivalent of 100 percent of the inside air volume is lost through cracks, seams and the opening and closing of doors every hour. Yet, only a 20 percent per hour air change is needed for normal ventilation. Table 1-1 lists the features of buildings with different infiltration rates.

A new house can be built to reduce infiltration to near zero, but infiltration in most existing buildings can only be reduced to about a 40 percent per hour air exchange. Air locks,* storm doors and windows, weather stripping, caulking air leaks and windbreaks made of shrubs or evergreens are effective methods of minimizing infiltration. To minimize the heat loss due to conduction and infiltration, analyze the cause for heat loss and adopt the appropriate remedy. Table 1-2 will serve as an initial guide.

Sixty percent of the heat lost from an uninsulated 1,370 square foot wood frame house is lost through the ceilings; 90 percent of the heat lost through the ceilings can be saved through proper insulation. Twenty percent of the house heat is lost through walls; through insulation to recommended standards this loss can be cut by 66 percent. Heat escaping through single pane windows and single doors accounts for 18 percent of house heat loss; multiple pane windows or storm windows and doors can save 50 percent or more with proper caulking and weatherstripping

*An air lock is an entry way such as an enclosed porch which creates a dead air space

Table 1-1. Building Features and Infiltration Rates

Building Component	One Air Change Per Hour	Two Air Changes Per Hour	Three Air Changes Per Hour
Building with cellar	Tight, no cracks, caulked sills, sealed cellar windows, no grade entrance leaks	Some foundation cracks, no weatherstripping on cellar windows, grade entrance not tight	Stone foundation, considerable leakage area, poor seal around grade entrance
OR			
Building with crawl space or on posts	Plywood floor, no trap door leaks, no leaks around water, sewer and electrical openings	Tongue and groove board floor, reasonable fit on trap doors, around pipes, etc.	Board floor, loose fit around pipes, etc.
Windows	Storm windows with good fit	No storm windows, good fit on regular windows	No storm windows, loose fit on regular windows
Doors	Good fit on storm doors	Loose storm doors, poor fit on inside door	No storm doors, loose fit on inside door
Walls	Caulked windows and doors, building paper used under siding	Caulking in poor repair, building needs paint	No indication of building paper, evident cracks around door and window frame

Source. **The Complete Energy-Seving Home Improvement Guide**, edited by James W Morrison, Arco Publishing Company Inc., New York, 1978

There are various measures, almost always cost effective, which can be taken to make an existing residence more energy efficient by minimizing heat loss due to conduction and infiltration. In order of their probable return on investment, they are: energy management; control of infiltration; heating system maintenance and modification; reduction of window loss; and the addition of insulation. A discussion of each of these measures which follows is taken from the findings of the Federal Energy Administration and the U.S. Department of Housing and Urban Development contained in the book **The Complete Energy-Saving Home Improvement Guide** edited by James W. Morrison (New York, Arco Publishing Co., 1978).

"The danger of measures is that they become ideals. You see it even in the thermostat. If we had no Fahrenheit, we would not be stabilizing our room temperatures too high. There is magic about the number 70 and we tend to stabilize the temperature at it, when for the sake of health it might be better at 64°."

Kenneth Boulding

Table 1-2. Heat Loss Causes and Remedies

Problem	Probable Cause	Remedy
Low house temperature High fuel use	High heat loss	Add insulation. Add storm doors and windows. Caulk and weatherstrip doors and windows.
Cold floors	Cold crawl space or basement, no insulation on floors	Add insulation to floors or basement walls
Drafty house	Loose doors and windows	Add storm doors and windows and caulk around windows and doors
Wet windows	Cold window surface or high humidity	Add storm windows or ventilate to reduce humidity
Wet walls or ceiling (uncommon complaint)	Cold inside surface or high humidity	Insulate wet surface or ventilate to reduce humidity

Source **The Complete Energy-Saving Home Improvement Guide** edited by James W. Morrison. Arco Publishing Company, Inc., New York, 1978

Home Energy Management

Home energy management applies to controlling the allocation of heat to different parts of a home at different times and offers the most energy savings for the least investment of time, effort or money:

Permanent thermostat setback from 72 degrees F to 68 degrees F will save approximately 14 percent of home's heating energy at no cost.

Nighttime setback from 68 degrees F to 55 degrees F over eight hours offers an additional savings of approximately 13 percent.

Daytime setback from 68 degrees F to 55 degrees F over eight hours offers an additional savings of approximately 11 percent.

Zoned control is desirable, though somewhat difficult to accomplish in an existing building. Ideally, heat should be supplied to each room according to normal activity patterns: kitchens often need less heat when the stove or oven is being used; dens and TV rooms need slightly higher temperatures to keep sedentary people comfortable, while bedrooms can be kept slightly cooler.

Lower thermostat on the water heater. Turn the water heater thermostat down one notch a day until someone complains that the water is not hot enough; then turn the thermostat back up a notch. The acceptable temperature range for hot water at the tap is between 120 degrees - 130 degrees F.

Close all curtains and shades at night to help prevent the loss of heat.

Take showers rather than baths as less hot water usually is used during a shower than a bath.

Control of Infiltration

Infiltration accounts for about 35 percent of heat loss in a typical home with reasonable insulation and may account for as much as 75 percent in a home with frequent, long door openings and closings. The following measures can help reduce infiltration:

Caulking, when done by the homeowner, is an extremely low-cost measure with high returns if properly done. Attention to detail is important, and the best available materials should be used—acrylics, polysulfides, polyurethanes or silicones—even though their cost is two or three times that of cheaper materials. Heat loss due to infiltration through wall and foundation openings may account for 10 to 15 percent of total heat loss. If caulking saves even half of this percentage, it would amount to savings of 5 to 8 percent—a practical investment.

Weatherstripping also pays high returns when done by the homeowner. Infiltration around windows and doors may account for 10 to 20 percent of total heat loss. As much as half of this can be prevented by weatherstripping. The best available materials should be used, i.e., thin spring metal strips or rolled vinyl. Careful application is important.

An airlock is especially valuable if there are frequent door openings and closings. Infiltration due to door openings ranges from 10 percent to 45 percent. Savings from a vestibule may be one-half of these figures.

A windbreak of closely spaced evergreens placed a distance of one to two house heights upwind from the dwelling may reduce infiltration 25 to 40 percent and heat loss by 10 to 15 percent.

Heating System Maintenance and Modification

Home heating systems are usually simple, sturdy and reliable devices which have changed little over the years. Recent fuel price increases, however, are sparking design changes on heating systems to increase their efficiency. Tips on maintaining heating systems and new design possibilities are described below. A local utility representative or building code inspector should be consulted before any changes are decided upon. And, all work should be performed by a competent heating contractor.

Annual maintenance and frequent filter changes are necessary for safety and efficient energy use. They should be considered routine.

Duct work should be checked for leaks and sealed in all areas.

Ducts in unheated areas should be covered with as much insulation as possible—up to six inches.

An automatic damper on the furnace flue or the use of outside air for combustion in a sealed combustion unit will save about 10 percent each on an average heating bill. An automatic damper slows the rate of flow of exhaust gases to the outside vent so that more heat is given up to the house. Sealed combustion has several advantages over an automatic damper; it is a safer, quieter, and more effective because it does not allow the furnace to draw inside air for combustion. Sealed combustion units will become more of a necessity for houses sealed with weatherstripping and caulking. Neither system is readily available at present.

Electronic ignition systems for gas furnaces could save at least 5 percent of the energy used in heating.

Resizing furnaces produces more efficient operation. Most existing furnaces are oversized because they have been designed for extreme temperatures rather than average winter temperatures.

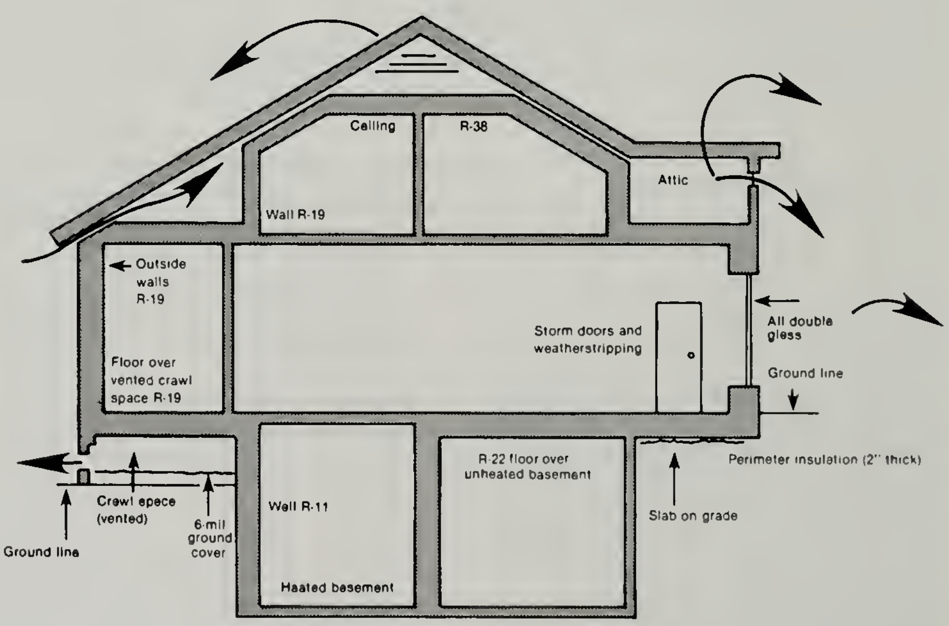
Reduction of Heat Loss Through Windows

Since the R value of single pane glass is .84 compared to about 11 for a fully insulated stud wall, it is easy to see why a typical house which has up to 20 percent window area loses so much heat through the windows. Storm windows and double pane windows can cut heat loss by one half. Triple pane windows will further reduce heat loss one third. Insulated shutters, drapes or shades are also recommended; of these, shutters are most effective.

Insulation

The addition of insulation is a necessary part of any residential energy conservation program and is most important for homes with little insulation. Since the knowledge and skill of contractors is quite varied, and since quality is difficult to assess or guarantee, a building owner should take time to ensure that he is getting a good job. Fire hazard and condensation on the insulating materials are both potentially significant problems which should be considered. Recommended insulation values are listed in Figure 1-4. Table 1-3 explains the advantages and disadvantages as well as suitable uses of different kinds of insulation.

Figure 1-4. Where to Insulate and Recommended Conservation Standards



Source Conservation Program, Department of Natural Resources and Conservation, Helena Montana, 1979

Conservation Measures for New Buildings

The conservation measures discussed for existing buildings are also applicable to new structures.

In 1978, the Mechanical Engineering Department of Montana State University in Bozeman investigated heat loss in new houses. Heat loss in a typical new house in Bozeman with 1200 square feet main floor and 1200 square feet floor area in a daylight basement revealed the following:

Infiltration	40%
Windows and Doors	27%
Ceilings and Floors (R-19)	12%
Walls (R-11)	21%

In the study, conservation measures reduced heat loss considerably. Infiltration was reduced by 63 percent with added care in the installation of doors and windows and with caulking and weatherstripping. By adding storm windows and storm doors, heat loss through windows and doors was reduced by 52 percent. Increasing the ceiling insulation to R-38 reduced heat loss 50 percent. Heat loss through the walls was decreased 34 percent by increasing the insulation in the stud walls to R-19 and by placing 1'' Styrofoam insulation on the concrete basement wall. All these measures cost about $2,000 (including labor) and are expected to pay back within five years.

Other important considerations for the energy efficient design of a new building are its topographical siting and its orientation with regard to the sun.

Table 1-3. Which Insulation Where?

Insulation	R per 1"	Pros	Cons	Suitable Uses
FLEXIBLE				
Mineral wool batts/blankets	3 10	Fire and moisture resistant; easy to install, widely available	Can irritate skin when handling; attached kraft paper wrapping can burn if unprotected	Walls, floors, attics, sloping roofs.
LOOSE FILL*				
Mineral fiber (rock, slag, or glass)	2 20-3.00	Easy to spread into open, flat spaces or blow into cavities	Can settle in walls	Attics, closed wall cavities
Cellulose	3 70	Can be blown; easy to get into nooks and corners	Can burn and absorb moisture unless treated; can settle and deteriorate.	Same as above
Vermiculite	2 10	Same as above	Lower insulation efficiency; absorbs moisture; can settle	Same as above plus masonry wall cavities
Perlite (volcanic ash)	2 70	Same as above.	Same as above.	Same as above
FOAMED-IN-PLACE				
Polyurethane	6.25	High R value, foam flows around obstructions to fill a space, then hardens to a rigid mass	Can burn, when ignited, gives off poisonous fumes, needs professional installation; can shrink, can burst closed cavities	Walls, attics, roofs, irregularly shaped construction; open cavities only
Urea formaldehyde (UFF)	4 20	Same as above, will not burst a closed cavity	Can give off irritating fumes, needs professional installation, can shrink	Walls, roofs, attics; open or closed cavities.
RIGID BOARD				
Polystyrene (extruded)	5 00	Impervious to water vapor and moisture, light weight, high R value	Will deteriorate if exposed to daylight; can burn and give off poisonous fumes; can dent if unprotected	Nonstructural wall sheathing, foundations (exterior or interior); nonstructural roof decks, masonry cavity wall.
Polystyrene (molded)	3 57	Light weight	Same as above, absorbs moisture	Nonstructural wall sheathing, foundations (interior), masonry cavity wall.
Polyisocyanurate	8 00	Light weight; high R value.	Same as above	Nonstructural wall sheathing, foundations (interior)
Polyurethane	6 25	Good resistance to chemical attack, not affected by light	Absorbs moisture can burn.	Same as above

*Labels on bags of loose fill should indicate the number of bags and the minimum thickness required to achieve typical R values such as R 19 30and 38

Source **Energy Conservation and You** U S League of Savings Associations Chicago

Topography

The topography—the lay of the land—affects air temperature, wind patterns, drainage patterns, and water availability. Depending on the topography, prevailing winds will be constricted or increased. Bottoms of valleys and ravines are likely to collect and trap cold air masses during the night and winter and should be avoided. Drainage areas as well as extremely flat or slightly depressed areas are also poor building sites. Sites should have at least a 2 to 4 percent slope for good drainage and ease of construction. Inclination and orientation of slope affects the amount of sunlight received and the resulting air temperature on the site.

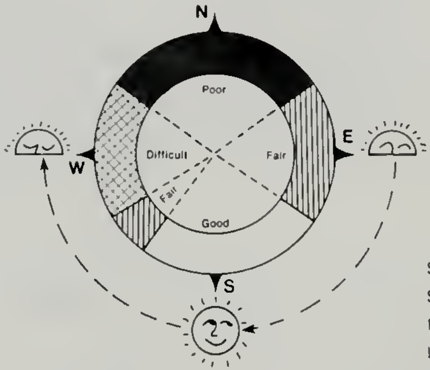
Sun

The design of a building's shape, orientation, and facades should take full advantage of the sun's natural heating capacities. In Montana, a building's shape ideally should be three times as long as it is wide. One of the long facades could then be oriented to the south to take full advantage of the sun's rays. A three to one ratio also insures that virtually every part of the house will benefit from the heat gained through the south-facing windows.

Depending on their placement, windows can be a source either of net heat gain or heat loss. To reduce heat loss, windows on the north, east and west should be minimized. to achieve heat gain, the window area on the south side should be maximized. Heat can be gained during the early winter morning by orienting a building slightly east of south. This orientation also provides shading during the summer because the sun's rays do not enter south-facing windows due to the sun's high position in the sky.

The position of rooms within the house can also maximize energy efficiency. Rooms in which you will be physically active particularly during the morning and midday do not require direct sunlight. Rooms where you will be relatively sedentary should be placed to receive direct solar gain (See Figure 1-5).

Figure 1-5. Orientation of Living Spaces



Space	N	NE	E	SE	S	SW	W	NW
SLEEPING	•	•	•	•	•	•		
SOCIAL				•	•	•		
FAMILY				•	•	•	•	
LIVING				•	•	•	•	
FOOD PREP		•	•	•	•			
PLAY SPACE				•	•	•		
STUDY		•	•	•	•	•	•	•
WORK/HOBBY		•	•	•	•	•	•	•
BREAKFAST			•	•				
LUNCH				•	•	•		
DINNER			•	•	•	•	•	
STORAGE	•	•					•	•

Orienting major-use rooms to the southern, or warmer exposure, makes maximum use of the solar energy.

An eastern exposure is second best, making the most of the morning sun. Southwestern exposures are adequate.

Western exposure presents difficulty in controlling low-lying late afternoon sun, and is also often the source of prevailing winds.

Northern exposures receive no direct solar radiation and therefore should be consigned to infrequently used spaces and those which require little or no heat. Spaces that are heated to a very low level or not at all offer very good insulating layers for these exposures.

If maximum shading from the sun is desired, the opposite from the above would apply, with easterly and northerly exposures being favored.

Source: **Your Energy Efficient House** Anthony Adams, Garden Way Publishing, Charlotte, Vermont, 1975

Earth Sheltered Construction

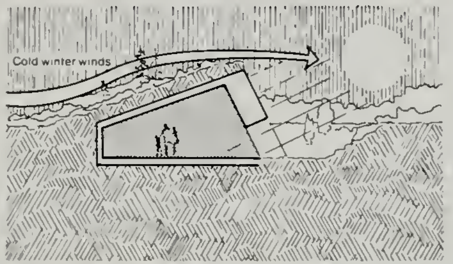
Earth sheltered construction is included in this conservation chapter because of its energy efficiency.

Earth sheltered construction includes both building below ground (below grade) and ground level structures with earth piled or "bermed" against the north, west and east exposures.

In earth sheltered construction, heat loss due to infiltration is minimized because the earth seals the buildings and conduction occurs more slowly since the earth maintains a relatively constant temperature and protects the building from temperature extremes. Table 1-4 provides the insulating values of different types of soils.

Figure 1-6 illustrates the basic features of earth sheltered construction.

Figure 1-6. Basic Features of Earth Sheltered Construction



Source **Underground Designs**, Malcolm Wells, Brewster, Massachusetts, 1977

Table 1-4. Insulating Value of Soils

	Thermal Conductivity*	"R" per foot
Light Soil, Dry	.20	5.
Light Soil, Damp Heavy Soil, Dry	.50	2.
Heavy Soil, Damp Concrete, Damp	.90	1.1
Wet Soil Average Rock	1.40	.71
Dense Rock	2.00	.50

*BTU per hour (sq ft × F day per foot)
Source **Underground Designs**, Malcolm Wells, Brewster, Massachusetts, 1977

The earth surrounds three sides of the building. Earth sheltered construction requires some special considerations about siting and building techniques. The following material comes from **Underground Design**, by Malcolm Wells, one of the pioneers in underground earth sheltered design.

Siting

Wells recommends a gentle south slope as the best terrain on which to build; it offers abundant sunlight and positive drainage. Low-lying depressions and pockets are to be avoided, as heavy, cold air will drain into them and frost and dampness will be exaggerated.

Structure

Underground structures around the country have been constructed with cast in place concrete, reinforced masonry and heavy timber. (See Figure 1-7 for different kinds of earth-covered construction).

To build an earth-covered roof, any structural system that is designed to take the load of the earth will work. The earth load can vary from 150 pounds per square foot for a roof supporting enough soil for small plants to 400 pounds per square foot for an earth roof capable of supporting small trees. In addition, a building code prescribed snow load also must be considered in the design of the roof. If the roof is to support people walking and playing, then pedestrian load also must be calculated into the design. Designing for these loads should be done by an engineer.

The exterior wall design down to one-to-two story depths can incorporate the same design and structural elements as any conventional below grade or basement wall construction. In all cases, however, the design must be based on actual soil, site and occupancy conditions. The smoother and simpler the exterior wall surface, the more reliable and economical will be the waterproofing/vapor barrier/insulation skin applied to it.

"If you are looking for answers to conservation problems, it seems to me to be a very bad beginning to label the interested public as 'consumers'. This encourages an attitude that is incapable of solving most of the problems. What can a consumer do? He can complain if it doesn't taste good - he can yell if he wants more - he can burp when he gets enough. None of this has much to do with solving problems directly."

Steve Baer

ANOTHER THEM POEM

Very clever of them
To define us as 'consumers':
It gives us the power
To open our mouths and eat
What they stuff in.

Wilbur Wood

Figure 1-7. Different Types of Earth Sheltered Construction

A
BERM

NEW EARTH LEVEL RAISED ABOVE EXISTING GRADE

B
CHAMBER

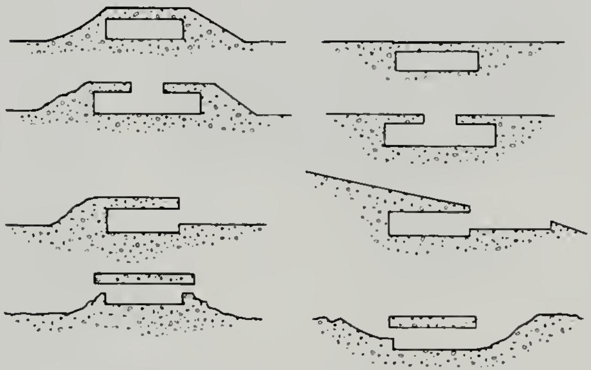
BUILDING EXCAVATED BENEATH EXISTING GRADE

1 "TRUE" UNDERGROUND, internally similar to deep space by its isolation

2 ATRIUM OR COURTYARD, used for entry, for light & air, for outdoor rooms

3 ELEVATIONAL, for windows, for doors, outside courts to accommodate slopes

4 SIDE WALL PENETRATIONS, for light, air, access, view; expansion potential



Source **Alternatives In Energy Conservation: The Use of Earth Covered Buildings**, The National Science Foundation, U.S Government Printing Office, Washington, D. C., 1976.

Water Proofing, Insulation and Vapor Barrier

In addition to structural design, waterproofing, vapor barrier and insulation are important. Parts of the building must be waterproofed (especially the roof; but generally not the walls, since the structure will be above the ground water level). Butyl sheeting, a synthetic rubber compound, is waterproofing material which is effective under severe water conditions. The butyl sheeting is placed directly on the roof concrete and under the insulation. Bentonite is also an effective waterproofing material.

Vapor proofing is necessary around the entire building shell because the earth around the building will generally contain more moisture than the air inside, creating a flow of moist air into the structure. In order to prevent this flow, a vapor barrier is applied to the outside of the shell. Remember that not all waterproofing materials are also vapor proof.

Insulation is placed on the outside of the building so that the building's walls can act as a thermal mass to store heat. Since the earth is colder during the winter months than the internal temperature of the dwelling, insulation is necessary to prevent heat from escaping. Earth itself is a poor insulator, but it does store heat and buffers the rapid temperature changes in the outside air. Earth stays warmer longer with the onset of winter; and with the onset of summer it retains winter's coolness. Consequently, heat loss from an underground building due to conduction and infiltration is slow because the difference in temperature between the inside air and earth will be much less than that of a building above ground.

Malcolm Wells recommends using blue board Styrofoam as the best insulation for earth sheltered construction (R = 4.99 per inch). With its closed cell construction, Styrofoam seems "to offer the best combination of moisture resistance, insulative ability, reasonable price and wide availability."

Ventilation

In most cases, ventilation of above ground buildings is not a problem because infiltration accomplishes the necessary ventilating of the building's interior space. However, in a well sealed underground building, infiltration will generally not be sufficient to adequately ventilate the building. Inadequate ventilation will result in an increase of water vapor inside the building because of moisture given off by people, plants, pets, cooking, and hot showers. If dehumidification is required, then mechanical dehumidification may be preferable to forced ventilation; it is less expensive than heating or cooling fresh outside air.

"The heat produced by human activity in New York City during the winter is greater than the amount of heat the city receives from the sun.

There are so many of us currently using so much of the planet's resources that we are altering the earth's climate."

Dr. Reed Bryson

"We are going to have to learn to do more with less, but that doesn't necessarily mean we will have to give up a lot of things that are dear to us."

Amory Lovins

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CHAPTER II

ACTIVE SOLAR SYSTEMS

Introduction

During the last few years, interest in solar technology has mushroomed and commercially available solar hardware has developed rapidly. More solar systems have been undertaken in Montana than any other renewable energy systems. These range from inexpensive, homebuilt greenhouses to large-scale, commercially manufactured active solar heating systems. Because of the rapid development of solar technology and its accessibility, active and passive solar systems are discussed more thoroughly in this handbook than other renewable energy systems.

The difference between active and passive systems is that active systems depend upon mechanical devices to distribute heat from the point of collection to the point of end use and passive systems do not. In a passive system, the structure itself is designed to collect, distribute and store the heat by means of natural convection and conduction.

Both active and passive systems operate upon the same principle — the conversion of light from the sun into heat. When light is transmitted through glass or plastic it heats an absorber plate in an active system or the thermal mass in a passive system. The absorber plate radiates the heat which is long wave radiation. The properties of glass and some plastics are such that light, which is short wave radiation, passes through while heat is blocked. This is known as the greenhouse effect.

The choice in applying solar technology is between an active system and a passive system. A few generalizations can be made regarding this choice in Montana. The most economic application of solar technology is domestic water heating, which usually requires an active system. Solar space heating of existing buildings also generally requires an active system. A passive system can be built into an existing building if that building is properly oriented with respect to the sun's path. For new construction, however, passive systems are generally more economical than active systems. Active systems allow more latitude in the design and layout of a building as well as its orientation on site.

The following topics on active solar systems are presented in this chapter: collector designs; air and liquid systems; siting the collector; distribution systems; heat storage—rock, water, eutectic salt, annual storage and solar ponds; installation and cost.

Collector Designs

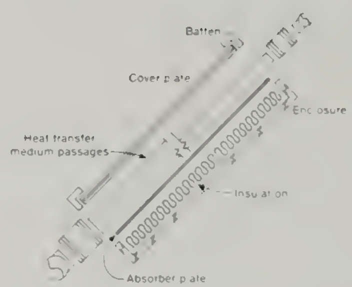
The basic components of an active solar space heating system are the collector; the heat distribution system — ducts or pipes, fans or pumps and a heat exchanger; controls — heat sensors and thermostat, and storage.

The collector is mounted at the appropriate angle to capture as much sun radiation as possible (placement of collectors will be discussed later). Collectors convert solar radiation into heat and use a circulating medium to transfer the heat from the collector into the building. This medium is either air, water, or an anti-freeze solution. There are two basic types of collectors: flat plate collectors which produce low temperature heat and concentrating collectors which produce low to high temperature heat. Flat plate collectors are more available commercially, less expensive and more reliable than are concentrating collectors

Flat Plate Collectors

A flat plate collector is essentially a blackened surface which will absorb the sun's rays and transfer the heat gained to either liquid or air circulated through the collector (see Figure 2-1). The flat plate is usually mounted in a fixed position at the best angle to the sun. A typical flat plate collector using water for heat transfer would consist of: (1) a corrugated sheet of metal about 4' by 8' painted flat black on top, insulated underneath and housed in a wooden box; (2) a network of piping attached to the metal to heat the water and take the heated water away to a storage area; (3) one or two layers of glass (single or double glazing) fitted onto the box an inch above the black metal surface to keep in the heat. Figure 2-2 illustrates liquid and air collectors.

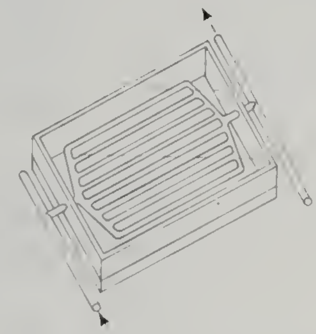
Figure 2-1. Flat-Plate Collector: An Exploded View



The flat plate collector is the most common solar collection device for space heating and domestic water heating in use today. The collector may be designed to use either gas (generally air) or liquid (usually treated water) as the heat transfer medium. Regardless of the medium used, most flat plate collectors consist of the same general components, as illustrated above.

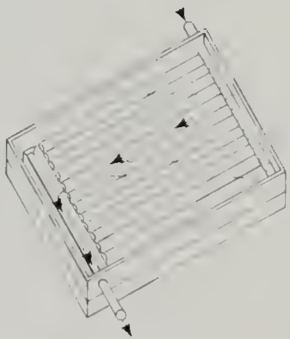
SOURCE: **Solar Industry Index**, Solar Energy Industries Association, Washington, D.C., 1977

Figure 2-2. Typical Flat-Plate Collectors



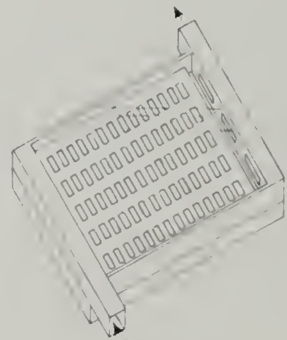
FLUID TUBE & PLATE COLLECTOR

Most flat plate collectors in use today employ water, oil or an anti-freeze solution as the heat transfer medium. The liquid is pumped through fluid passage ways attached to or integral with the absorber plate. There it is solar heated before being circulated through storage.



TRICKLING WATER COLLECTOR

This type of collector uses corrugated metal panels. Liquid "trickles" down the corrugated channels from a manifold at the top to a trough at the bottom of the collector. The heated water then flows by gravity to the storage tank.



FLAT-PLATE AIR COLLECTOR

Air collectors circulate air or other gases through or over the absorber plate, returning heated air through the ducts to storage or the living space.

Source: **Solar Industry Index**, Solar Energy Industries Association, Washington, D.C., 1977

Figure 2-3. Collector Cross Section Showing Heat Loss

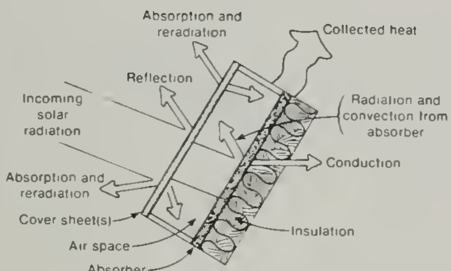


Figure 2-4. Refractive Concentrator

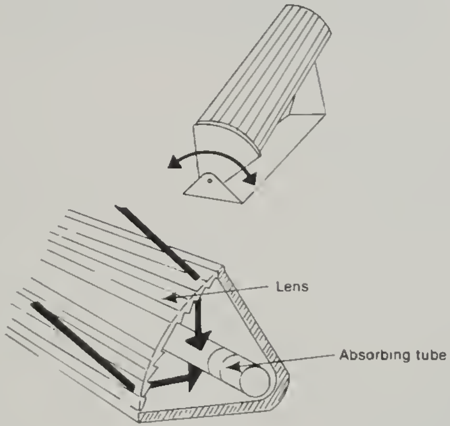
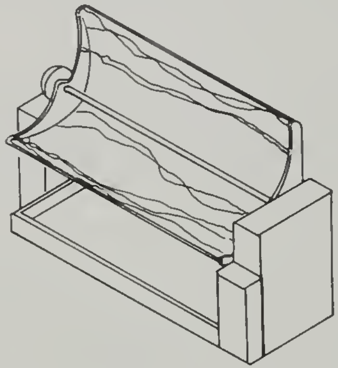


Figure 2-5. Trough Collector



SOURCE Solar Industry Index, Solar Energy Industries Association, Washington, D.C., 1977

The efficiency of a flat plate collector is determined by the percentage of energy striking the collector's surface (glazing) that is converted to heat within the collector. Flat plate collector efficiencies are lowest when sun angles, insolation (incoming solar radiation) and outside (ambient) air temperatures are lowest A low sun angle means that the incoming solar radiation is diffused over a wide area and conversion of that sunlight to heat will be comparatively inefficient. A collector can yield efficiencies of up to 55 percent on a clear summer day for three hours each side of solar noon—the time of day when the sun is highest in the sky. Efficiency is also affected by the positioning and tilt of the collector. For maximum efficiency during the heating season, collectors in Montana should face near true south (about 19° west of magnetic south) and be tilted about 60° from horizontal.

The efficiency of a flat plate collector is ultimately limited by its design. One hundred percent efficiency is impossible because some of the incoming solar radiation is immediately reflected by the outside glass. Also once the radiation is converted to heat, some of the heat escapes back through the glazing and some is conducted through the bottom of the collector (see Figure 2-3).

Concentrating Collectors

Concentrating collectors use reflective surfaces such as mirrors or reflective metals or lenses which bend (refract) light to concentrate it onto a relatively small area. Concentrating collectors can achieve substantially higher temperatures (350° F and higher) than flat plate collectors. Examples of concentrating collectors follow:

A refractive concentrator (Figure 2-4) is especially efficient because:

a) it tracks the sun by moving on its axis and therefore receives more sun

b) the design of the lens allows a greater percentage of thermal energy to pass into the absorbing tube; and

c) the rate of heat loss from the collector is low.

Linear or trough concentrating collectors (Figure 2-5) employ a concave surface which concentrates radiant energy onto the collecting tube running down the middle of the trough. These collectors can also be designed to track the sun

Parabolic concentrating collectors (Figure 2-6) employ a dish type reflector to concentrate radiant energy onto a point of collection. These collectors are mounted on a gimbals arrangement to track the sun on more than one axis. Parabolic collectors are the most commonly used collectors when very high temperatures are needed.

One drawback of all concentrating collectors is that they collect only the sunlight coming from the direction in which they are aimed. They do not collect the solar energy from light that has been diffused by clouds, air borne particles or reflected from the ground as do flat plate collectors. Concentrating collectors are also more expensive than flat plate collectors and require more maintenance.

Figure 2-6. Parabolic Collector

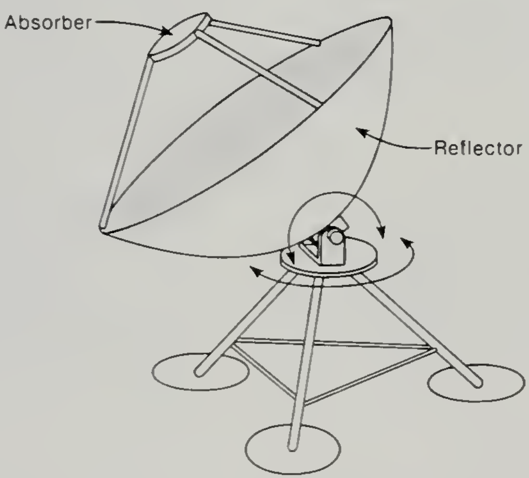
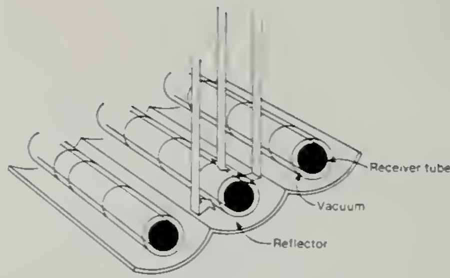


Figure 2-7. Evacuated Tube Collector



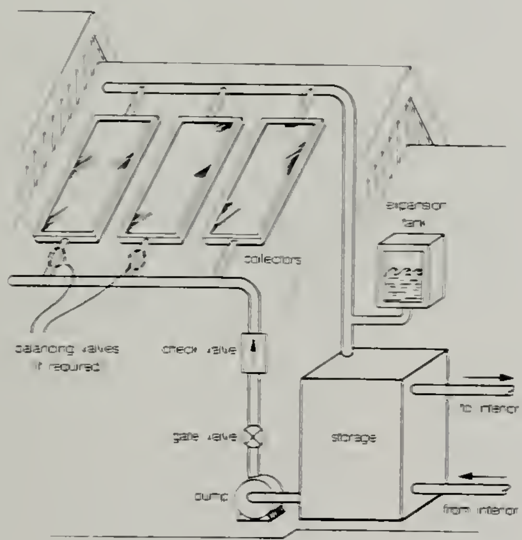
Evacuated Tube Collector

Another type of solar collector, an evacuated tube collector, is illustrated in Figure 2-7. The evacuated tube collector is composed of a series of three concentric cylindrical tubes, with a vacuum between the outer and middle tubes and a black selective coating on the outer surface of the middle tube. The tubes have the advantage that almost the same amount of surface area is exposed and perpendicular to the sun at any time during the day. Water or air is circulated from supply pipes through the inner tube. Upon reaching one end of a collector module, the water or air enters the volume between the inner and middle tubes where it reverses flow direction and continues to build up heat content. It is then drawn off by the return tube and circulated into the heating system. An evacuated tube system has the advantage of higher collection efficiency at standard operating temperatures, and the utilization of high temperatures in its collection process without excessive heat loss. The vacuum between the outer tubes of glass helps lessen conductive and convective heat loss. The disadvantage of these collectors is that they are very expensive

Active Air and Liquid Solar Systems

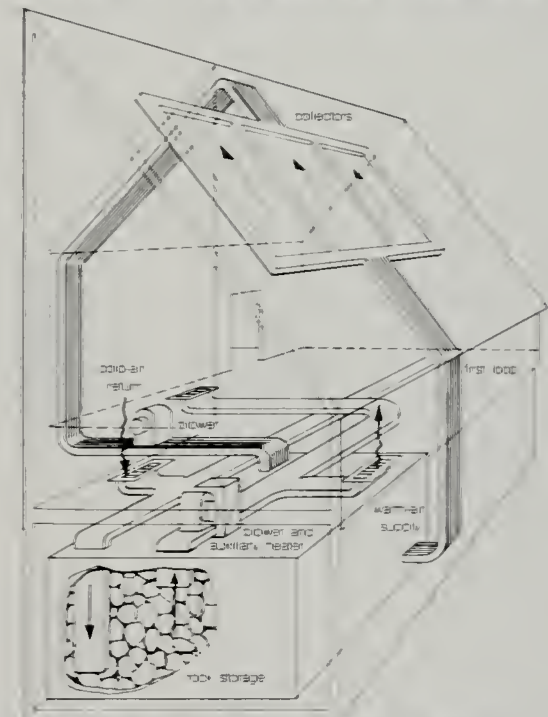
Active solar heating systems are classified as either air or water systems depending upon whether the heat transfer fluid which passes through the collector is air or a liquid (typically water or a water/antifreeze solution). Figures 2-8 and 2-9 show detailed layouts of typical liquid and air active systems which provide both heat and domestic hot water. Discussion of the detailed design of such systems is beyond the scope of this handbook and is covered in depth in numerous publications (see bibliography at the end of this chapter). In Montana, air and liquid systems are comparable in terms of system performance and cost. Table 2-1 lists the advantages and disadvantages of each system. For space heating, either system, properly designed, can be effective. The air system's summer cooling potential and lack of freeze problem make it look particularly attractive in Montana. However, since liquid systems at the present time are more common than air systems, there is a wider choice of components and installers. This is especially true with respect to solar domestic water heating systems.

Figure 2-8. Typical Active Liquid System Layout



SOURCE: *Other Homes and Garbage: Designs for Self-Sufficient Living*, Jim Leckie et. al., Sierra Club Books, San Francisco, 1975.

Figure 2-9. Typical Active Air System Layout



SOURCE: *Other Homes and Garbage: Designs for Self-Sufficient Living*, Jim Leckie et. al., Sierra Club Books, San Francisco, 1975.

Table 2-1. Advantages and Disadvantages of Water and Air Systems

Water Systems		Air Systems	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
1 Water is a cheap, efficient heat transfer and storage medium	1 Can have higher initial costs than air systems	1 Leaks, if they occur do not present potential for major damage	1 Leaks are hard to find and lower heating efficiency considerably
2 Piping from collectors to storage is incorporated easily into most homes This is particularly important if a retrofit installation is being planned Pipes do not require a lot of floor space	2 Water must often be treated with chemicals to prevent corrosion, mineral deposits and algae build up in the piping	2 Air systems are not as subject to contamination as are water systems	2 Rock storage requires almost three times the volume of water storage
3 Water is more energy efficient to move than air is it is cheaper to pump water through a water system than it is to blow air through a rock storage bin	3 Chemical water treatments are often toxic and can cause problems if they leak into the potable water system	3 Air systems cannot freeze and are not subject to corrosion	3 Air ducts take up more usable floor space than water pipes
4 Water-to-air and water-to water heat exchangers are more efficient than air-to-water and air to air heat exchangers and require less heat exchange area than air systems	4 Leaks in the plumbing system are potentially damaging to the home and its contents	4 In areas with hot summer days but cool nights (as in much of the Pacific Northwest) the rock bed storage unit can be cooled with outside air during the night and used to keep the building cool during the day Part of the solar heating system can be used as a summer cooling system	4 Collectors and storage may need frequent cleaning unless filters are used in the system The rock bed storage in some areas must be protected from dust which requires the installation and periodic servicing of duct filters
	5 Freeze protection of some sort must be employed	5 For space heating, air can be effective at much lower temperatures than water The air can be vented directly from the collectors to the living space thereby, avoiding temperature drops or heat losses inherent in heat exchangers	5 Heat exchange is not as efficient with air systems as it is with water systems
			6 The ducting required for an air system is often harder to incorporate particularly when retrofitting older homes
			7 In humid areas an air system s rock bed storage unit may provide an environment for the growth of fungus and mildew which might give circulated air an odor

Source **The Oregon Sun Book** Hal Brown Oregon Department of Energy Salem Oregon 1977

Sizing a Flat Plate Collector

Since flat plate collectors are the ones most commonly used, the following information was developed especially for these collectors. Sizing a flat plate collector requires a determination of the number of square feet of collector needed to provide the desired space and/or water heating requirements on an annual basis. The efficiency of a particular collector is the percentage of the total energy of solar radiation falling on its surface that the collector actually converts into deliverable heat. However, percentage of heat supplied can be a misleading index of the actual efficiency of the solar collector and the efficiency of the whole solar system.

Collector efficiency is related to the difference in temperature between the air inside the collector and the outside air. As the temperature differential increases, collector efficiency falls rapidly. Although a collector's efficiency determines the maximum amount of heat that will actually be delivered to a building, the efficiency of the rest of the heating system also must be taken into account. Heat is lost in the ducts or pipes, the pumps or fans, and in the heat exchangers. While the collector may be 60 percent efficient, the system as a whole will not be much more than 30 percent efficient This means that an active solar system will deliver about 30 percent of the total solar energy which strikes the collector.

Before calculating the collector area for a particular application, estimate the annual heat requirement of the building, and the available solar energy. See Appendix B, page 83 and Appendix C, page 87 for formulas on these calculations. The computations can then be applied to a sizing method, using the f chart (see Appendix D, page 93 for f chart and sample calculation).

Siting the Collector

Flat plate collectors can be mounted on the roof, at a tilt, vertically on a south facing wall or free standing in the yard in an area that is free of shadows during the heating season. These areas can be located on a skyline chart; the procedure for using this chart is explained in Appendix E, page 95. As has been discussed, the efficiency of the solar system is affected by the orientation of the collector as well as the slope of the collector. A technical discussion of the effect of orientation and slope on collector efficiency is to be found in the Appendix D This discussion reveals that some efficiency is sacrificed if collectors are mounted vertically However, there are some advantages to vertically mounted collectors Advantages and disadvantages of sloped and vertical collectors are presented in Table 2-2.

Table 2-2. Advantages and Disadvantages of Sloped and Vertical Collectors

Sloped Collectors: Advantages	Sloped Collectors: Disadvantages	Vertical Collectors: Advantages	Vertical Collectors: Disadvantages
1 Maximum solar penetration per square foot	1 Misses reflected light from snow	1 Captures reflected light from snow	1 Approximately 6 percent loss of solar penetration per square foot
2 Captures more of the diffuse radiation from overcast skies	2 Relatively difficult to build	2 Can be protected from summer sun by use of an overhang Relatively easy to build	2 Misses most of the diffuse radiation from overcast skies
	3 Tendency towards snow and ice buildup	3 Can be mounted flat on a wall	
	4 Needs summer cooling in all climates	4 No tendency toward snow and ice buildup	
	5 Complicates interior planning	5 Simplifies interior planning	
	6 Requires roof penetration to mount	6 Easier to clean	
	7 More problems with snow and wind		

Source **Nicholson Solar Energy Catalogue** Nick Nicholson Renewable Energy Publications Quebec Canada 1977

Distribution of Heat From the Collector

Heat from the collector can be transported either to the storage system and/or to the living space. Transportation of heat is the most mechanically complicated portion of the entire solar system. Discussion of the technology of distribution is too complex to treat in this handbook; however, a general description can be offered in this section.

In a liquid system, fluid (either water or an anti-freeze solution) is pumped into the collector where it is heated and then pumped from the collector to a storage tank and/or through radiators for immediate use. If an anti-freeze solution is used, the system must employ a closed loop to prevent contamination of the domestic water supply. The anti-freeze solution is pumped from the collector through a heat exchanger and returns to the collector to repeat the cycle. The heat exchanger transfers heat from the anti-freeze solution to the potable water through conduction.

In air systems, fans force air through the collector where it is heated. The hot air is then blown through ducts to rock or salt storage and/or to the living space for immediate use. Some air systems employ an air to water heat exchanger where the air gives up its heat to water. The heated water is available for domestic use and/or for space heating.

Short Term Heat Storage Systems

Rock, Water and Eutectic Salts

To fully utilize an active solar system, thermal storage is essential. During certain periods, the collector produces more heat than is necessary for space and/or water heating. If that heat is not to be lost, it must be stored and later used. Heat may be stored by raising the temperature of substances such as water (for active water systems) or rocks (for active air systems) or eutectic salts.*

Rock and Water Storage

The air collector-rock storage system circulates air through the solar collectors; the heated air is ducted to storage and/or directly to the building for immediate use. A bin of washed rocks ½" to 1½" in diameter is used for storage; hot air flows through the spaces between the rocks and heats them. The twisting path of the air stream through the rock bed ensures efficient heat exchange.

*Whenever a solar system provides less than 100 percent of a building's annual heating load and has only short term storage an auxiliary or backup heating unit is necessary. This backup heating system can be a conventional gas or electric furnace or a wood burning unit If electric backup is used with an active liquid system, an electric heating element can be installed to heat the storage tank, thereby, eliminating the expense of an additional distribution system

"Renewable energy sources and small scale technologies are necessary changes but if they're still being used to do the same things, we really haven't made any strides towards a better society."

Tom Bender
Rain Magazine

In the liquid collector/liquid storage system, hot water for the collectors can circulate directly through the building's system or be sent to the heat storage tank. Storage is provided by a large tank holding 400 to 1000 gallons usually located in the basement. In most installations 1.5 to 2.5 gallons of water are needed for each square foot of collector space; thus, a water storage tank for a 500 square foot collector would require about 1000 gallons capacity and take up approximately 140 cubic feet. The equivalent rock storage for a 500 square foot collector would take up approximately 420 cubic feet, or three times the volume needed with water.

There is disagreement about the relative merits of rock vs. water storage systems. Some energy specialists believe that the large space needed in a rock system is compensated for by the economy, convenience and lack of maintenance associated with air/rock solar systems. They contend that rock is superior to water as a substance for solar storage because the stored heat in rock is given up more slowly than the stored heat in water, making it more suitable for the regulation of home heating.

But Dick Dill, a Sentinel High School science teacher and solar manufacturer from Stevensville, Montana, believes that water storage is superior to rock. Dill argues that the inability of rock to give up large quantities of heat on demand is a disadvantage. He also contends that "the static pressures encountered and hence the fans required to move the air around are horrendous. An air system on my own shop required a 1600 cfm fan powered by a 1/3 hp motor to push a small amount of air through 180² ft. of collector without any rock storage. I could do the same job easily in water with 1/35th hp."

Dill explains that the biggest problem encountered with rock storage is that the incoming air takes the path of least resistance. He cites an example of a rock storage system in which the incoming air did not circulate throughout the bin, but flowed through only 10 percent of the rock storage. Since only 10% of the rocks are heated the heat stored is far below the capacity of the storage bin. Moreover, because the stored heat eventually flows to the rest of the storage area, the temperature drop decreases the quality of the heat available for space heating.

Another advantage of water storage over rock, Dill maintains, is that a water storage tank will generally contain three distinct thermal layers. Each of these layers has a different temperature, the top layer being the hottest. This thermal layering can be used to draw the appropriate grade of heat from the water storage by engineering outlet pipes which can tap water from each layer. For example, for space heating water can be drawn from the top (about 150° F); for domestic hot water from the middle (about 130° F); and for laundry from the bottom (about 110° F).

Eutectic Salt Storage

Heat may also be stored through the use of eutectic salt systems. Now in production, these systems permit greatest heat storage in the smallest space. The following information comes from an article by Paul F. Kando, "Eutectic Salts," in **Solar Age** (April, 1978).

The "heat of fusion" principle behind eutectic salt storage may be understood through the simple use of ice cubes to cool a drink. The drink cools because the ice absorbs heat from the liquid. The heat absorbed, however, does not raise the temperature of the cube, but melts it instead; i.e. intensifies the molecular motion within the cube until it changes from the rigid crystal structure of solid ice into the liquid water phase. The amount of energy absorbed by a 32° F ice cube as it becomes 32° F water is called its heat of fusion. It is equal to the amount of heat removed from the water by refrigeration when the ice cube was made.

Very large amounts of heat can be stored as the latent heat of fusion of eutectic salts. A pound of Glauber's Salt, the most widely studied and used, absorbs 104 BTU as it melts at 90° F and about 21 BTU as its temperature rises another 30° F. To store the same 125 BTU over the same rise would require about 4 pounds of water or 20 pounds of rock.

Much smaller storage volumes are possible with eutectic salts. Consequently, they offer the designer unusual versatility in locating the heat storage. Closets, thin partitions, structural voids, and other small spaces become likely heat storage bins. To some extent, we can return to the passive concept of integrating heat storage volumes into the normal building components. And because the storage temperature remains close to the room temperature, especially with Glauber's Salt, little insulation is needed around the storage volume.

With so many things to recommend them, why haven't eutectic salts seen widespread use? Until recently, the major problem was the separation of components after partial melting had occurred, rendering the salts useless after several cycles of melting and freezing. Another problem has been the supercooling of the solution. Dr. Maria Talkes has recently solved these problems; more than 1,000 cycles have been tallied and further experimentation is upping the count.

The remaining hurdle to full-scale use of eutectic salt is an economic one. Eutectic salts capable of storing a million BTU can be prepared for as little as $200, but the cost of containers can quadruple that price. Rigid plastic tubes seem to offer the best short-term hopes of solving the problem. With luck, the next decade should see real commercialization of eutectic salts for storage.

A note of caution: So far, heat of fusion storage design and construction is beyond the capabilities of the average do-it-yourselfer. While not particularly dangerous to handle, the chemicals involved must still be handled with care. Mixing procedures are critical. The filling and sealing of containers requires special equipment and knowhow for longlasting reliable system performance. Experience shows that while not necessarily detectable at the outset, all shortcuts (like the omission of the thickening agent) lead to significant degradation of performace within a few operating cycles.

Salts cannot store high temperature heat above approximately 90° F. Therefore, very large amounts of air must be used to transfer much heat to the living space.

Annual Storage

Since most solar systems can store only three to four days of heat, during the summer when solar gain is most intense, the system must be shut down because there is no place to store the heat. In December, January and February the immediate heat demand is greatest, but the daily insolation is minimal. However, if thermal storage were large enough to store heat from the summer months, then advantage could be taken of the high availability of solar insolation on an annual basis. The collectors can operate full time and are more economical to operate ($ per BTU per year) than a system with short term storage which must be shut down during the summer.

A study in Toronto cited in **Solar Age** magazine (April, 1978) shows that by using annual storage a solar system can supply virtually all of the heat necessary for a building with less than half of the collector area needed to heat in December and January. With careful design, this savings in the required collector area can offset the higher costs of the larger storage required. Annual storage systems also have a virtual immunity to short-term weather variation, whereas the heat from short-term storage systems can be depleted during a few days of inclement weather. An annual storage system eliminates investment in an auxiliary conventional heating system and fuel payments for the auxiliary system.

Solar Ponds

A novel solar collector which doubles as a thermal storage system is the solar pond. The following information comes from an article by Zangrando and Bryant in **Solar Age** magazine (April, 1978). A salt gradient solar pond is an efficient low-cost solar energy collector and long-term storage system for low temperature heat. Any body of water collects a large amount of energy from the sun, but it cannot store heat to any great extent. In general, the water temperature remains below the ambient air temperature because heating the top layer of water results in convective circulation which transports the heat back to the surface where it dissipates into the air. But there are some natural salt lakes which display unusual thermal behavior — temperatures at the bottom are substantially higher than those at the top. This difference in temperature is a result of non-uniform vertical distribution of salts which prevent convection and the consequent heat loss. These naturally occurring salt lakes prompted scientists to propose the creation of artificial solar lakes to harness the energy of the sun through storage of heat in the lower convective layer of the solar pond.

Figure 2-10 illustrates the cross section of a solar pond with three distinct layers: fresh water, insulation layer and convection layer.

The solar pond is divided into layers with varying density of salt. In the upper layer the salinity content varies from zero at the surface to maximum concentration at the boundary. In the convective layer, salinity is at maximum concentration. Since water is a poor conductor of heat and does not allow infrared radiation to pass through it, the salinity gradient allows the solar flux, which is most visible and ultraviolet, to penetrate deeply, effectively trapping the energy in the pond's lower depths.

A full scale demonstration pond has been in operation at the University of New Mexico for more than two years. In its second year of successful operation, the storage layer reached 198° F.

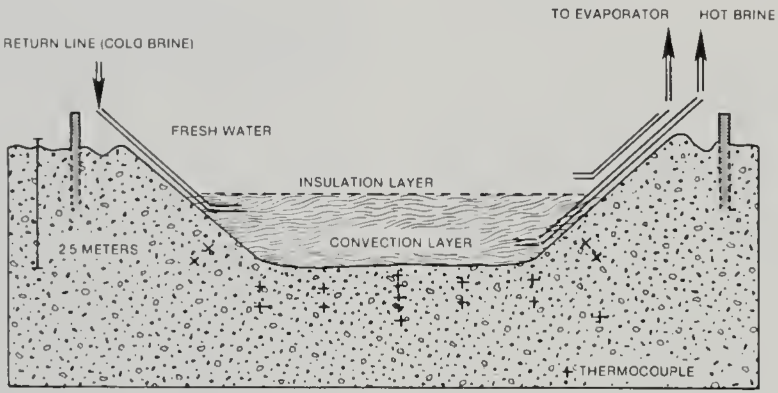
The model pond is designed to supply the hot water and space heating requirement of an 1800 sq. ft. house in Albuquerque, New Mexico. This amounts to approximately 33 megawatt hours per year of useful heat. Heat is extracted by direct circulation of hot brine from the convective layer into a heat exchanger. The brine is pumped out of the convective layer through a heat exchanger, then returned to the convective layer through a diffuser. Although the solar pond has operated successfully, instances have occurred when the salinity gradient has broken down and the heat lost to the atmosphere. Researchers are modifying the design of the pond to prevent the reccurrence of such instances.

In rural areas of Montana, solar ponds could provide virtually all the space heating and domestic hot water requirements ot a farm or ranch house. In urban and suburban areas, solar ponds could provide heating for several residences or businesses at once. Table 2-3 lists the construction and installation costs of the New Mexico pond which has a collection area of 1,130 square feet.

"When you are at the brink of an abyss, the only progressive move you can make is to step backwards."

Alwyn Rhys

Figure 2-10. Solar Pond Cross Section



SOURCE "A Salt Gradient Solar Pond" Federica Zangrando and H. C. Bryant, **Solar Age**, April 1978

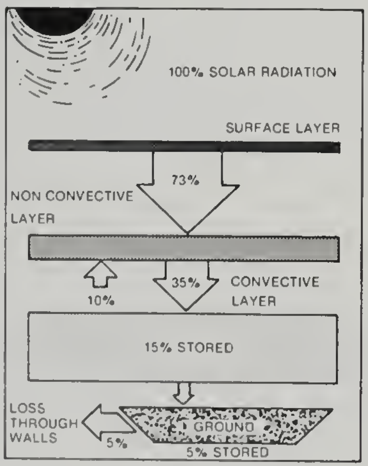


Table 2-3.
New Mexico Solar Pond Cost

Excavation	$ 900
Hand Labor	400
Liner (30 mil Hypalon reinforced)	1,500
Salt, 40 tons	1,400
Pumps, piping, heat exchangers	1,500
TOTAL	**$5,700**

Economics of Active Systems

Because an active solar system requires a substantial initial expenditure (i.e. front end cost) compared to conventional heating equipment, the expense of a system is an extremely important consideration. Solar systems with short term storage will require a backup heating unit. Also, choosing the most economically sized system is dependent upon an accurate prediction of the system's performance.

Any economic comparison of the added initial cost of an active solar system and a conventional heating system must consider a projection of costs and savings over the lifetime of the systems (life-cycle costing). It is misleading to compare the high initial cost of solar installations with the initial cost of a conventional heating system, because fuel for a solar system is always free, whereas fuel for conventional systems costs money and is subject to rising prices. Over an extended period of time, therefore, some solar systems will not only pay for themselves, but eventually will start saving their owners money when compared with the lifetime costs of conventional systems. However, the high initial cost tends to make solar less attractive than conventional heating systems to the homeowner.

As yet, there is not enough experience with modern, commercially available systems to predict how long such a system will last, but it seems reasonable to assume a 20-year lifetime for air and water systems. Around the nation there are some systems that have been in operation for at least 20 years and show no signs of deteriorating. Australian water heating systems have operated in excess of 15 years with essentially no maintenance and also show no signs of breaking down.

Most economic analysis of active solar systems estimate collector costs at $15 a square foot and base (non-collector) costs at $2,500. Maintenance costs are about $35/year and operating costs about $.10/ft²/year. If a typical active solar system has 160

ft² of collector area, then total system cost is about \$6,000 over a 20-year period exclusive of interest:

Collector cost @ \$15/ft²	160 ft²	=	\$2,400
Base cost @ \$2,500		=	\$2,500
Maintenance cost @ \$35/year	20 years	=	\$ 700
Operating cost @ \$ 10/ft²/year	160 ft² x 20 years	=	\$ 320
	Total system cost		\$5,920

If the entire \$6,000 is borrowed at 10 percent per annum over 20 years, the annual payment can be calculated according to the following formula:

$$\text{Annual Payment} = \frac{i}{(1 + i)n - 1} + i \quad x\ P$$

where,

i = interest rate, expressed as a decimal
P = amount borrowed
n = number of years of the loan

P = \$6,000
i = 0.10
n = 20 years

$$\text{Annual Payments} = \frac{.1}{(1.1)20 - 1} + .1 \times 6000$$

$$= \$705/\text{yr.}$$

cost would be 20(705) = \$14,100, of which \$8,100 is interest.

This computation does not take into account state and federal tax savings for renewable energy systems. See Appendix F for details on tax credits.

These costs do not tell the whole story, however, it is also necessary to compare the costs per unit of heat of a conventional fuel system with the solar heating system. Estimate the total annual heating load by determining the heating requirement for each degree day (see Appendix B), and then multiply that requirement by the number of degree days in the year. For example, if a house in Billings requires 10,000 BTU/Degree Day, and in Billings there are 7049 Degree Days in a year, multiply 7049 by 10,000 to get an average annual heat load of 70,490,000 or 7.05×10^7 BTU/year. If a solar system provides 50 percent of the annual heating requirement, then it will supply about 3.5×10^7 BTU/year.

To compare the cost of producing a unit of heat from the solar system with a unit of heat from a conventional heating system, first convert BTU into kwh to compare the solar system with electric resistance heating or into equivalent cubic feet of natural gas to compare that solar system with gas heating. One kwh is equal to 3.4×10^3 BTU; a solar system which supplies 3.5×10^7 BTU/year supplies an equivalent of 1.03×10^4 kwh/year. Since the cost of the solar system is about \$705/year, the cost per kwh is \$0.068/kwh [\$705 ÷ ($1.0^3 \times 10^4$ kwh)] compared to \$0.025/kwh for electricity from the local utility at 1978 rates. Similarly, one million cubic feet of gas (1 mcf) produces about 9×10^5 BTU. Consequently, the solar system provides the equivalent of about 38.9 mcf per year [$(3.5 \times 10^7) \div 9 \times 10^5)$]. The solar cost per mcf is \$18.12 (\$705 ÷ 38.9 mcf), compared to \$2.40/mcf for natural gas at 1978 prices. The total cost of heating with a solar system which provides 50 percent of the annual heating requirement includes the cost of the conventional fuel required to meet the other 50 percent of the annual heating load. At 1978 prices, the total cost of heating with solar is 4.3 times the cost of heating with natural gas alone and 1.9 times the cost of heating with electricity alone.

Although the above figures show that the solar system is not cheaper than conventional heating systems, one important consideration has been left out of these calculations: the steady rise in conventional fuel costs. A study by Solar Planning Office West in Denver assumes that electric rates will rise 8 percent a year and gas will rise 12 percent a year. In twenty years the electrical rates could be as high as or higher than:

$$(1.08)^{20}\ (\$0.205/\text{kw-hr}) = \$.112 \text{ per kw-hr}$$

and the gas rates as high as:

$$(1.12)^{20}\ (\$2.40/\text{mcf}) = \$23.13 \text{ per mcf.}$$

Therefore, by 1998 electricity may be expected to cost \$.112/kwh and gas to run \$23.15 per mcf (if gas is available in sufficient quantities by that date). If rates rise to these levels, then active solar systems for space heating will probably be cost effective.

Other cost variables also should be kept in mind. If a solar system is bought outright with no interest payments, the cost drops to about \$0.029/kwh which competes more favorably with the present cost of electrical resistance heating. Furthermore, initial costs can be cut significantly if a system is made from recycled or inexpensive material and fabricated and installed by the homeowner.

Buying an Active Solar System

The following material on buying an active solar system is excerpted from **The Connecticut Solar Handbook**, published by the Connecticut Citizen Action Group, 1978.

Judging the Collectors' Quality

1. *What kinds of temperatures will your collectors get? It may sound odd, but flat-plate collectors absorb more BTU per square foot at lower temperatures than at high temperatures. An average temperature range for an efficient BTU output from a flat-plate collector is between 100° and 200° (it should, however, be able to withstand much higher temperatures, up to 350° to 400°. This way, if it overheats, the collector will not melt, or burn, or be otherwise damaged).*

Do not pay attention to any claims intended to impress you with the high temperature Brand A flat-plate collector can get. High temperature does not mean high efficiency!

2. *Has the collector been tested by an independent testing laboratory? Do not buy a collector which has not been tested in accordance with standard federal tests by a laboratory totally unconnected with any manufacturer. The testing should be done in accordance with the National Bureau of Standards/ASHRAE requirements, which are part of the HUD Minimum Property Standards. Compliance with the HUD Minimum Property Standards is a requirement for eligibility under the HUD solar grant program.*

   Ask the dealer for a copy of the test results, and the laboratory(ies) where the testing was done. (Do not take NO for an answer!) Call the laboratory to double check the test results, even if it is located in Arizona or Florida.

   Look very carefully at the dealer's claims regarding efficiency and test results. One solar manufacturer/dealer, for instance, claims his collector

   ...was tested by a university engineering laboratory in accordance with the National Bureau of Standards (NBS) specifications. The dealer claims the test report states that the collector's efficiency "is the highest value measured so far at this test facility."

   This is misleading because it doesn't tell you what you need to know. When were the tests done? How many tests have been done since the collector was tested? As it turns out, this was the fourth collector tested in the fall of 1976, and many collectors have been tested since then, which could very well have had higher efficiency values.

Check the Systems' Cost

1. *How much does the collector cost per BTU per square foot? Knowing the cost per BTU per square foot is the most accurate way to figure out the cost of the collector. It is not enough to know the cost per square foot of the collector. You must know the cost for how much heat is produced per square foot. One dealer may offer you three times more collector area for a certain price than another dealer. But if that collector size does not also give you three times more heat, it is not worth the price.*

2. *What does the cost include, and what doesn't it include? You usually get a better deal if a dealer can offer to sell a whole system, not just the collectors and one or two of the other parts. A whole system includes collectors, heat exchanger, storage tank, pumps, valves, fans, controls, thermostats, and at least some of the collecting piping...*

   Also when you buy a whole system, especially a solar domestic hot water system, from one dealer, you can be more assured of the workability and compatability of the different parts as a whole.

3. *Does the cost of the system include installation and labor? Installation...is about 1/3 of the total cost of buying a solar heating system. Make sure you know whether you will have to pay for it separately.*

How Do You Select a Solar Dealer?

1. *Check the dealer's professional credentials. What is the dealer's experience working in fields related to solar energy, like plumbing, carpentry, mechanical engineering, or the heating, air conditioning or refrigeration business?*

   Does the dealer have a good reputation in non-solar work?

   Can friends and neighbors vouch for the competency of the dealer's work?...

2. *Make sure the dealer has a stable, reasonably successful business. How long has the dealer been working in your geographical area, in both the solar and non-solar fields?*

3. *Check the dealer's experience with solar heating systems. How many systems has he or she sold in the state?*

   ....The dealer should be able to show you a demonstration system in operation. If the dealer will give you the names of other customers that have installed systems, call each of these people and ask: (a) How is the solar unit working? (b) Has the dealer responded promptly to any questions or problems?....

4. *Make sure the dealer provides all claims about the solar system and services in writing. This is for your own protection. Unless a claim is in writing, you can never prove the dealer ever promised it....*

5. *Make sure the dealer provides you with written warranties on the materials and workmanship of the system. Is it a FULL or LIMITED warranty? A full warranty is the best. If it is a limited warranty, make sure you know what is covered and what is not covered. Who will pay for repairs and parts replacement under the limited warranty?*

   How long will it take the dealer to reply to a service claim under the warranty? Your system should be fixed within at least two weeks after you contact the dealer.

   Are the warranty terms transferable to the new owners, if you decide to sell your home?

6. *Ask for a copy of the Owner's Instruction Manual. The dealer should provide you with: (a) Clear, readable, directions about every part of the system. (b) A full diagram of what the system will look like.*

7. *Make arrangements with the dealer about the system's installation. Will the dealer install the system and take complete responsibility for the system's installation? If so, has the dealer been trained by the solar system manufacturer?*

   The dealer should be able to show you a certificate of training if he or she plans to install the solar heater. Also, if the dealer installs the system, make sure the warranty covers labor and service, as well as workmanship and parts.

   If the dealer doesn't install the system, can he or she recommend an installer? How much

responsibility will the dealer take for the installer's work?

If the dealer recommends an installer, he or she should be able to tell you about the installer's background, experience and credentials. The dealer also should be willing to supervise the installation, and to come and check the system out after it has been installed.

If the dealer will make no arrangements, and will take no responsibility for the solar installation FIND SOMEONE ELSE. Remember, the installation is as important as the system, and they cannot be treated as two completely separate responsibilities.

How Do You Select a Reliable Solar Installer?

1. *Check the installer's professional credentials. Does he or she have a plumbing license, or a general contracting license? If not, does he or she work with licensed plumbers or contractors to install solar heating systems?*

2. *Check the installer's experience with solar heating equipment. Insist on seeing the installations in operation similar to the one you want to buy. Not any competent plumber can put in a solar unit—it takes a practical knowledge of the special aspects of solar technology.*

3. *Make sure the installer gives you a written estimate of the job's cost. The installer should examine your house before giving you an estimate. The estimate should include everthing he or she will do.*

4. *Insist on a written warranty for service and labor. Exactly what services and maintenance will the installer perform under the warranty?*

   Will the installer continue to service and maintain the system after the warranty period is over—at what cost?

   Will the installer check out the system periodically after it is operating? It should be checked at least once within a month after installation.

5. *Make sure you know the whole system will work. The installer should talk through the whole system with you. He or she should explain the reason and function for every part.*

6. *Insist on knowing what you can do to care for and maintain your solar system. It will cost you less, if you can care for your own solar unit, and if you can fix minor problems which plague any new heating system. Find out:*

   How do you clean the system?

   How can you fix a small leak?

   What can you do if the pump or fans break down?

   How and when to refill and drain the system, if it is necessary?

   Ask simple, practical questions such as: "If something goes wrong which valve will help, which pump controls what, what plug do I pull?

How Do You Make Sure the Solar System is Properly Installed?

Look at the whole system carefully. Compare it to the diagram in the owner's manual, and make sure nothing is missing...Some of the major things to check out with the installer:

1. *Are the roof mountings secure? Are they anchored well enough to withstand hurricane-strength winds? If the collector is mounted directly next to the roof, is there a weatherproof seal between the mounting and the roof to protect against leakage, mildew or rotting?*

2. *Is all of the piping well-insulated? Inside and outside piping should be insulated to an R-4 or R-5 level. Outside pipe insulation should be weatherproof.*

3. *Are the roof penetrations, where the pipes enter, sealed tightly? Sealing the penetrations well is important to protect against leaks and against heat loss from the pipes.*

4. *Are the pumps and/or fans all facing the right direction? A simple but necessary thing to check.*

5. *Are the pumps and/or fans the right size for the system? If they are too small, they will cut down on efficiency. If they are too large, you will be wasting electricity and cutting down on your overall savings from the system.*

6. *Is your storage tank (or storage rock-bed) well-insulated, at least R-11 to R-20, and tightly sealed? Heat losses from the storage tank must be prevented, or you will be using the back-up system more than necessary, and wasting your potential savings.*

7. *If you have a liquid system, does it have a pressure relief valve and an expansion tank? In case the system overheats, a pressure relief valve and an expansion tank are needed to take the extra pressure off the system and prevent damage.*

8. *How do you know there are no leaks in the system? Before putting the system into operation, the installer should pressure test the system to show you there are no leaks. Insist on this pressure test, and learn what the operating pressure of the system is, and should be. Regularly check the pressure gauge to make sure the system is working correctly.*

A final important question to ask the installer is:

How can you tell whether the system is working well and collecting heat? There are instruments that should come with the system to allow you to keep track of how it is working. One simple way is to place thermometers on the pipes running to and from the collectors, and in the storage area. Keep track of the temperatures daily and you will be able to follow the changes in heat input in accordance with the changes in weather. (If thermometers do not come with your system the installer should provide them).

"There is more to life than increasing its speed."
Mahatma Gandhi

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"There is a certain (and I hope undeniable) rightness one finds when working with alternative energy. This derives from knowing that it is afterall possible to share this planet without doing irreparable harm to it, and from realizing that we have not yet forgotten the uncollectable debt we owe nature."

David Oien
Conrad, Montana

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Solar Energy Published bi-monthly, this is the technical journal of the International Solar Energy Society. It contains scientific papers reporting results of solar energy research around the world. From Permagon Press, Hedington Hill Hall, Oxford, England OX3 0BW.

Solar Energy Digest presents pertinent news on solar and solar-related energy. Published monthly from Box 17776, San Diego, CA 92117.

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CHAPTER III

PASSIVE SOLAR SYSTEMS

Introduction

The passive solar effect is a common occurrence. For example, the passenger section of a car (particularly one with dark interior colors) is a natural solar collector. The sun's rays pass through the car's windows and are absorbed by the interior and re-radiated as heat. If the windows are not open, the interior of the car stores and collects the heat, making it unbearable and even dangerous to the occupants. The passive solar effect also is experienced in most homes. The dog lying in a patch of sunlight on the floor, the sunny room in the afternoon — these are examples where windows are working as passive solar collectors.

Because active systems depend upon proper installation and durable machinery for reliable operation and efficient performance, they require careful attention to detail in construction and installation, and continual maintenance. Passive solar systems do not rely on fans or pumps to move a heat transfer fluid and require little maintenance; they are the simplest way to harness the sun for space and water heating.

The passive solar system works in the following way. Sunlight penetrates a glazing substance (glass, plastic); it then falls upon a thermal mass (brick, stone, masonry or water used to form a wall or floor). The thermal mass converts sunlight into heat which is absorbed and stored. As long as there is a temperature difference between the thermal mass and the surrounding air, the thermal mass will continue to give its stored energy to the surrounding space long after the sun goes down.

As simple as passive design is, there are many variables which affect system efficiency. The most critical variable is the positioning of the building's collector space in line with the path of the sun (see Appendix E). Other important variable qualities are the composition of the glazing, its thickness and number of layers, the composition of the thermal mass, and the architectural design of the building. In this chapter, passive systems (direct gain, thermal storage, and greenhouses) are discussed in terms of their sizing and design, their application to existing homes, and their performance and cost.

> *"Once you have built your house like a thermos bottle, you take the idea one step further, you aim it towards the south and put a cork in it."*
>
> David Wright
> Solar Architect

Direct Gain

The simplest type of passive system is the direct gain approach in which there is an expanse of glass, usually double glass which faces south, and a considerable thermal mass such as a poured concrete floor and concrete walls with insulation on the outside (see Figure 3-1). The building is comfortable all year since the south face is exposed to a maximum amount of solar energy in the cold winter months when the sun angles are low and a minimum amount of solar energy in the summer when the sun angles are high.

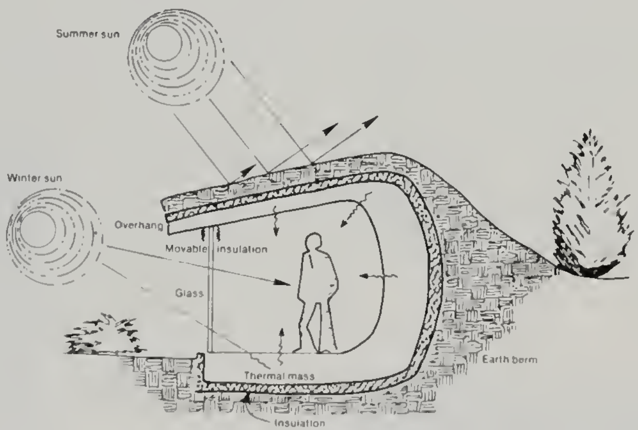
In a direct gain system, the thermal mass stores heat, and insulation on the outside of the mass prevents heat loss to the building's exterior. Shutters can be mounted on windows to prevent the loss of heat at night through the glass. The direct gain system soaks up day time heat and releases it slowly.

Thermal Storage Wall

A second type of passive system is the thermal storage wall. In this system, heat is stored in a wall several inches behind the south-facing glazing. The thermal storage wall is usually painted black or a dark color to facilitate absorption. The wall can be made of masonry or containers of water. During the day, the sun heats the outside surface of the wall. The heat is then slowly conducted through the wall reaching the surface and then radiated into the living space (see Figure 3-2).

Common applications of the storage wall concept are the trombe wall (Figure 3-3) and the water wall (Figure 3-4). The trombe wall not only radiates heat into the living space through the thermal mass, but also convects air heated in the space between the glazing and the wall into the living space. The warm air rises and circulates through the top part of the trombe wall into the

Figure 3-1. Direct Gain Passive Solar System



Design principles: Southern orientation of glass, unshaded in winter, protected against hot summers by man-made or natural shade. Thick, heavily insulated walls.

Source **Passive Solar Heating of Buildings**, J D Balcomb et al., Los Alamos Scientific Labratory, Los Alamos, NM

Figure 3-2. Thermal Storage Wall

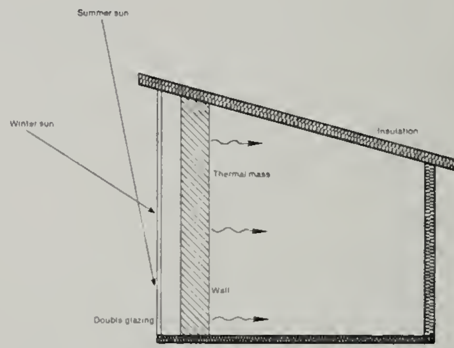
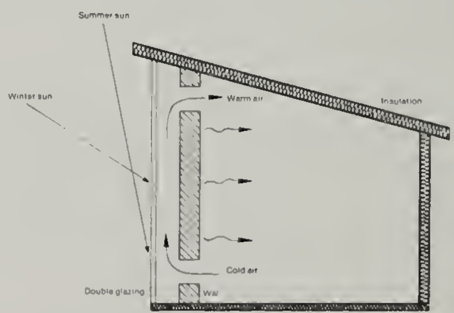


Figure 3-3. Trombe Wall



living space as the cooler air at the floor of the room is drawn through the bottom part where it is heated and convected back into the room. About 30 percent of the heat provided by the trombe wall system to the living space comes from this thermocirculation path. Typically, the outside surface of the wall which faces the glazing heats up to 140 degrees to 150 degrees F during the day. The inside surface temperature remains at about 85 degrees, providing radiant and convective heat to the room.

Greenhouse

Another type of passive system is the solar greenhouse. The solar greenhouse combines the features of direct gain and thermal storage wall techniques. A greenhouse is often built onto the south side of the building with some kind of thermal storage wall between the greenhouse and the house. A greenhouse can also be built as a separate unit. During the winter, solar energy normally provides most of the heat required for

Figure 3-4. Waterdrum Wall

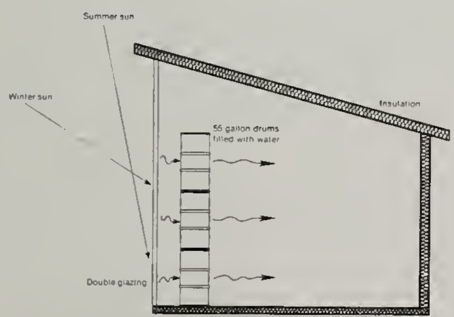
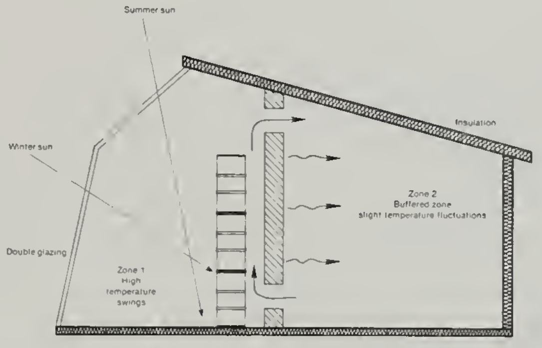


Figure 3-5. Attached Solar Greenhouse



the greenhouse as well as some heat to the rest of the house (see Figure 3-5). Design consideration for greenhouses is discussed later in this chapter.

Sizing Passive Systems*

Sizing the passive components of a building for space heating is a matter of determining the square footage of glazing as well as the amount and composition of the thermal storage mass (the floor and walls of the collector space). The dimensions of the glazing determine the amount of light which enters the building, while the composition and thickness of the thermal mass determines the amount of heat that can be stored and the time and rate at which it is released.

When sizing and designing passive systems, the objective is to minimize temperature fluctuation within the building. Unlike an active system with a differential thermostat and other control mechanisms, a passive system achieves temperature control primarily through the correct sizing of its glazing and thermal mass as well as manual or automatic operation of insulation shutters and vents. If a passive system is incorrectly designed and sized, the interior spaces will be subject to extreme temperature fluctuations, creating uneven heat distribution throughout the interior.

A well insulated and heavily constructed thermal mass is particularly important in all passive systems if temperature fluctuations are to be minimized. The following graph (Figure 3-6) depicts the fluctuations of the inside air temperatures of two houses. One house is light 2×4 wood frame construction and the other is heavy construction with considerable concrete and brick enclosed by insulation on the outside. During the tests reported by the Mechanical Engineering Department of MSU, neither home was heated by an auxiliary system. The home with heavy construction and insulation has minimal fluctuation in the inside air temperature and is the more comfortable of the two.

*The technical information contained in this section is from the research of Ed Mazria, Steve Baker and F. C. Wessling of the University of New Mexico

Figure 3-6. Temperature Fluctuations Over Time as a Function of Construction

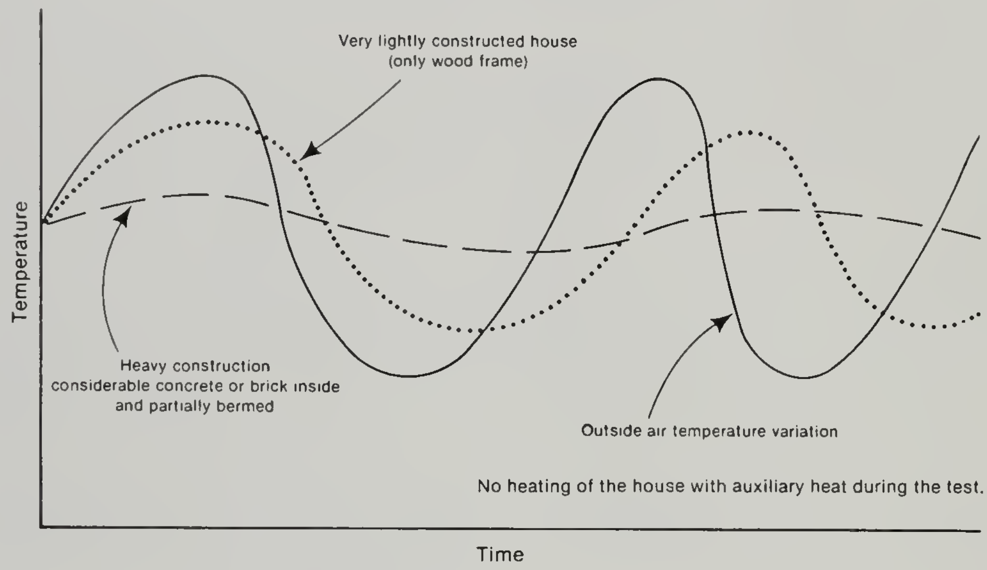
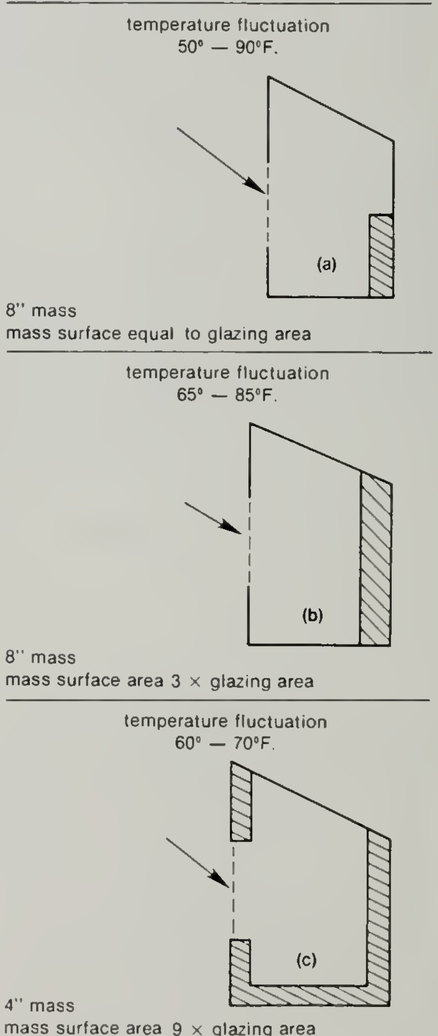


Figure 3-7. Thermal Mass Configurations



To achieve about 50 percent (or greater) of the annual space heating requirement in a direct gain system, south facing windows equal to 25 percent of the total floor area are necessary The windows should be double glazed.

Researchers at the University of Oregon have experimented with different thermal mass configurations within a test cell, keeping the dimensions of the glazing constant. Figure 3-7 illustrates three different configurations. Design C, which has a 4'' thick thermal mass with a surface area nine times the surface area of the glazing results in the least temperature fluctuation over a 24 hour period

Configurations (a) and (b) reveal that a small thermal mass cannot absorb heat as rapidly as it enters the dwelling which heats the air at an excessive rate and overheats the space. With the larger surface area of the thermal mass in configuration (c), the incoming light is spread over a much larger area, and is converted to heat, stored and re-radiated over a greater period of time. The thickness of the thermal mass should be at least 4''; anything thinner does not provide adequate thermal storage and creates large and uncomfortable temperature fluctuations.

Another factor which has an effect on internal temperature fluctuation is the composition of the thermal mass. Some materials are more effective heat storage mediums than others. In Figure 3-8, the effectiveness of different materials on inside temperature is shown. The results of the tests from which the graph is

constructed demonstrate that the major factor of the composition of the thermal mass bearing on system performance is the materials' relative thermal conductivity (the quality or power of transmitting stored heat to other mediums). The higher the thermal conductivity of the material, the more readily that material accepts or rejects heat. Material with a low thermal conductance may need a high temperature difference to force a moderate heat flow resulting in wide temperature fluctuations in the living space. Material with high thermal conductance may need only a small temperature difference to force heat flow which can also result in wide temperature fluctuations.

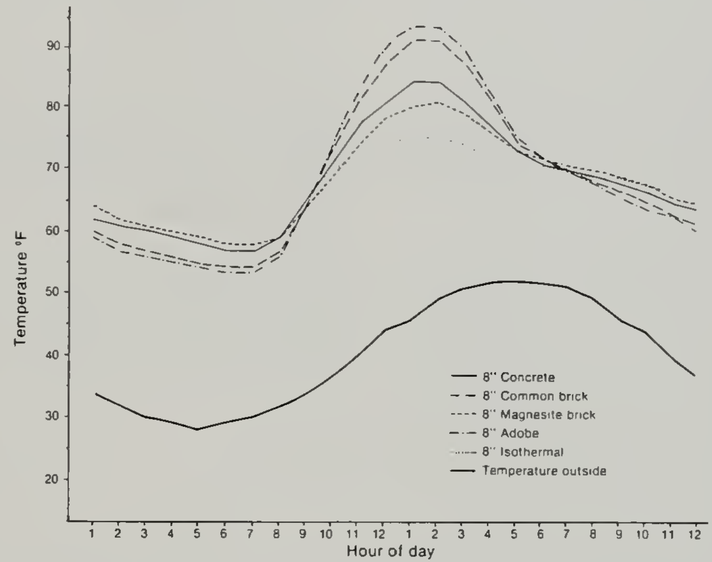
Of all masonry materials, magnesium-additive brick yields the most consistent temperature performance. But even more consistent is the 8'' isothermal wall — a water wall. Ideally, the isothermal wall should be made of water encased by steel; in practice, a drum wall with water encased in metal barrels or fiberglass columns filled with water is used. A water (isothermal) wall can easily be used in a trombe wall system but not in a direct gain system because of the design and construction problems associated with using water for thermal storage along the interior walls and the floor. Virtually all direct gain systems employ masonry material for thermal mass.

Current design information suggests that to achieve 50 percent of annual space heating with a trombe wall system, the double-glazing surface area must be half the total floor area. The trombe wall's surface area must also be 50 percent of the floor area and if it is not a water wall it should be composed of dense concrete at least 12'' thick.

Doug Balcomb, who does solar research at Los Alamos Scientific Laboratory, has developed the following "Passive Rules" regarding glazing and thermal mass for all passive systems.

#1: 2 to 3 feet² of south-facing double glazing should be used for each BTU/°F-hr. of additional thermal load. This will give at least 50 percent solar heating in Montana for a building kept within a temperature range of 65 degrees to 70 degrees F.

Figure 3-8. Comparison of Thermal Materials



Source. **Predicting the Performance of Passive Solar Heated Buildings**, Ed Mazria, et. al., Architectural Department, University of Oregon, 1977

#2: A thermal storage capacity of at least 30 pounds of water or 150 pounds of masonry or rock should be used for each square foot of south glass. This storage should be located in the direct sun. If not located in the sun, four times more storage is needed.

#3: The best thickness of a trombe wall is in the range of 12 to 16 inches. The masonry should have a high density — at least 100 pounds per cubic foot. Thermocirculation vents can be used to increase daytime heating but will not increase night time minimums. Vents should have lightweight passive back-draft dampers or other means to prevent cooler night air from flowing into the living space.

Further Design Considerations for Direct Gain and Trombe Wall Systems

Although much literature on solar building design urges that an overhang be constructed to block the summer sun to prevent overheating, in practice an overhang is not necessary in Montana. The summer sun rises high enough in the sky so that little direct sunlight enters south-facing windows. However, in a direct gain system, glare can be an acute problem during the winter heating season because the sun is low in the sky. There are various shading devices that can be employed with a direct gain system to reduce glare. Shading devices such as awnings, and blinds are effective, although they will decrease heat gain to some extent.

Structurally, both the direct gain system and trombe wall require much more concrete than conventional construction, but no new skills or technologies are required. A new construction technique (tilt-wall construction) for concrete trombe walls is being used in California and seems quite promising. Rather than pouring the wall upright, the entire wall is poured on the horizontal, allowed to dry, and lifted upright. Special care must be taken to insure that the wall rests on good footing and is safe and reliable; technical help may be necessary.

The thermal conductivity of the concrete trombe wall and, thus, its performance, increases over time as the residual moisture is baked out of the concrete. Generally, there should be at least 4'' - 6'' of space between the glazing and the trombe wall. Enough space between the glazing and the wall should be left to facilitate cleaning and to lower and raise an insulating curtain to prevent heat loss through the glazing during the night.

Insulating the glazing area to prevent night time heat loss is necessary during a typical Montana winter. Insulation can be accomplished through the use of external or internal insulating shutters, internal beadwall insulation where bits of styrofoam are mechanically blown between the two layers of glazing, or through the use of insulating curtains. In some particularly effective designs, night insulating devices may prove unnecessary. A direct gain home that California architect David Wright designed for a family living in Cody, Wyoming has performed so well that no night insulation devices have been installed, although the original plans called for such devices.

With the trombe wall, heat loss through the glazing at night can be decreased by preventing the warm interior air from flowing through the top vent into the space between the glazing and the wall, and at the same time preventing cold air from flowing into the interior space through the bottom vent. The vents can be shut manually or automatically by using a plastic sheet attached in such a manner that when warm air attempts to flow through the top vents and cold air through the bottom vents the air pressure seals the plastic tight as is shown in Figure 3-9.

In any passive system, there must be enough south-facing glass to ''charge'' the system daily. There are various options which allow the design of the south-facing glass to be vaired. Clerestory windows, skylights and ''suncatchers'' furnish light to the interior space not directly adjoining the southern wall and are illustrated in Figure 3-10.

If one of these glazing options is used in a building's design, thermal stratification, where the warmer air accumulates at the top of the structure, must be minimized. Casablanca fans (large ceiling fans) are relatively economical means to prevent thermal stratification.

Figure 3-9. Trombe Wall with Operable Vents

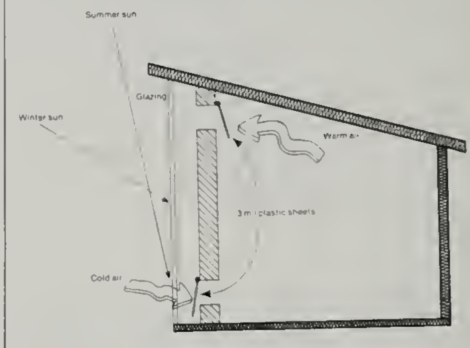
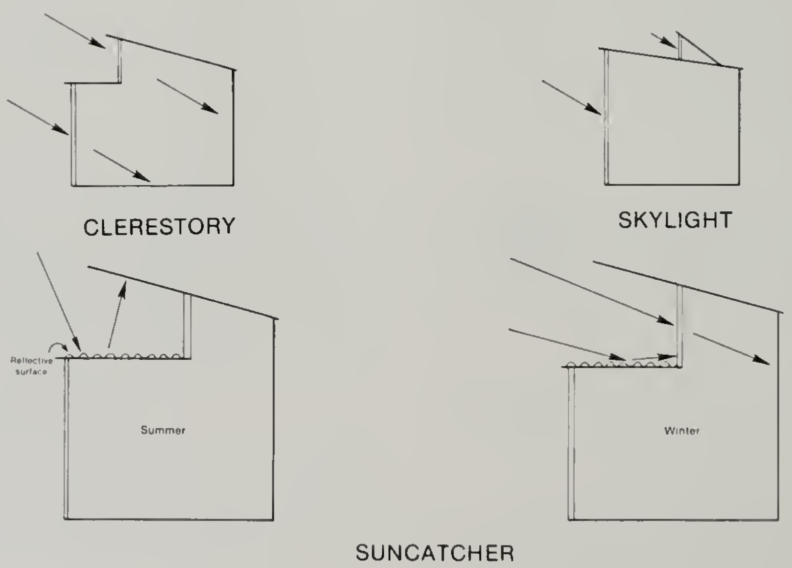


Figure 3-10. Window Options



The Direct Gain and the Trombe Wall Systems Compared

With new construction, a choice must be made (in most cases) between a direct gain system and a trombe wall system. An attached greenhouse can be incorporated with either system. Table 3-1 compares these systems.

Solar Greenhouse: Design Considerations

W. F. and Susan Yanda have written extensively on solar greenhouse construction and design. Figure 3-11 is a diagram of one of their greenhouses.

In their booklet, **An Attached Solar Greenhouse** the Yandas suggest the following design considerations to keep in mind before building is begun:

> *Southern exposure is necessary for a good solar greenhouse. However, the structure may be as much as 40 degrees to the east or west of south and still be functional (see Figure 3-12).*
>
> *No large obstructions should block the winter sunlight from the greenhouse. Not more than an hour or so of morning or late afternon sunlight should be lost.*
>
> *The greenhouse may adjoin a home or other building to the advantage of both. If possible the greenhouse should enclose a window, door or combination of these to maximize its heating potential. Take advantage of natural features — for example, a fruit tree might shade the unit in the summer and not block much winter light.*
>
> *[In Montana,] a door on the east side makes sense because the prevailing winter winds are usually from the northwest. Also plan a low southwest vent and a high northeast vent for cross circulation.*
>
> *Use all possible "tie-ins" to the house. If the home has overhanging eaves, they make excellent connections to the greenhouse rafter. The vertical walls of the unit should be well secured to the home. The vertical studs of a frame home tie in easily to the greenhouse walls.*
>
> *Plan the location of the solid walls. Not all walls of the greenhouse need to be clear. Build mass into the greenhouse and insulate as much as possible without giving up too much sunlight. The fewer clear areas, the less heat lost at night. A balance must be struck between plenty of sun and plenty of insulation.*
>
> *Make sure that drainage can be diverted from the greenhouse.*

Table 3-1. Direct Gain vs. Trombe Wall Systems

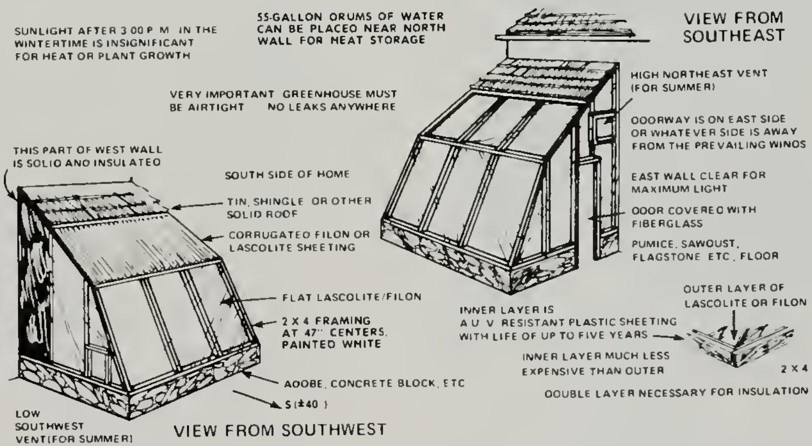
DIRECT GAIN

Advantages	Disadvantages
• scenic view remains intact	• glare
• high efficiency of conversion of incoming light to usable heat	• intense light can fade materials and furniture finishes
	• cannot use rugs on floor or the storage area will be curtailed
	• a large (expensive) amount of masonry is necessary
	• easy to overheat in the winter
	• difficult to maintain temperature control

TROMBE WALL

Advantages	Disadvantages
• minimizes concrete	• loss of view to the south
• less temperature fluctuation than in a direct gain system	• cannot use the wall to hang pictures etc as that would decrease the effect of the thermal mass
• better and easier temperature control than direct gain	• can lose heat back through the trombe wall
	• loss of floor space

Figure 3-11. Basic Solar Greenhouse



Source: **An Attached Solar Greenhouse**, W F Yanda, Lightning Tree, Sante Fe, New Mexico, 1976

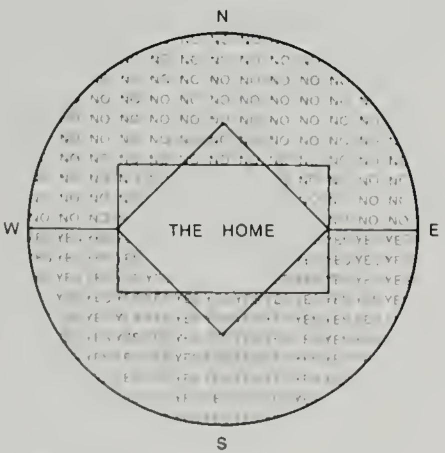
If possible, locate the greenhouse around or near an outside faucet to make watering easier.

A way to obtain more vertical space in the greenhouse is to dig out the area it will occupy. A depth of 12-18" is advised. This depression can later be filled with loose insulation. Note: Do not exceed the depth of the house foundation.

Depending on the materials used, the cost of a greenhouse will vary considerably. Glass is more expensive than fiberglass, but it will not deteriorate when subjected to high solar intensity, moisture and air pollution. High grade fiberglass, however, generally will not deteriorate appreciably for at least twenty years.

Fiberglass glazing seems to diffuse light better than glass and is better for plant growth. And because fiberglass requires less structural support, less light is blocked by supporting members. For a cheap double glazing, polyethylene plastic can be used on the inside surface of the primary glazing.

Figure 3-12. Acceptable Solar Greenhouses Exposure



Source An Attached Solar Greenhouse W F Yanda, Lightning Tree, Santa Fe, New Mexico, 1976

If the greenhouse is used to grow plants, light, temperature, relative humidity, and the growing area must all be optimized. Special care should be taken in the design of the growing beds and in the storage and walkways to maximize the growing area. For a small greenhouse, one half of the total floor space generally will be used for storage and walk space.

Retrofitting an Existing Building with Passive

To provide an adequate passive system to a building not originally designed for such an energy-saving option is seldom cost-effective. However, there are a number of options which can help in the passive heating of an existing house, including window box collectors, the construction of a trombe wall and the attachment of a solar greenhouse or window greenhouses to the structure.

Window box collectors (also known as natural convection collectors) are simple devices which can help heat individual rooms for a low cost with no remodeling required (see Figure 3-13). When these collectors are well designed, their performance can equal or exceed that of most active air systems. Figure 3-13 is an illustration of a window mounted U-tube air heating collector. The collector surface behind the glazing is heated by the sun and in turn gives off its heat to the air within the collector. This air expands, becomes lighter and flows from the collector into the room as denser, colder air from the room flows into the collector. This convective flow takes the form of a U and will continue as long as the sun heats the absorbing surface behind the glazing.

Performance of U-tube collectors is quite good. For a U-tube collector placed below the area to be heated, daily efficiencies (the amount of actual heat collected) of 40 to 45 percent are typical on sunny days when collector temperatures are running 50 degrees F above the outdoor temperature.*

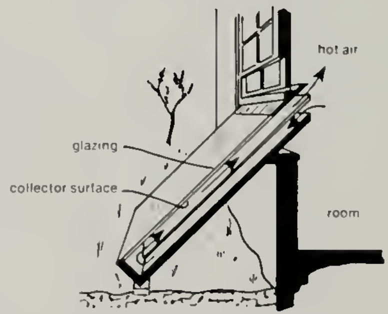
*"Natural Convection Collectors," W Scott Morris, **Solar Age**, September, 1978

Constructing a trombe wall in a retrofit situation requires replacing a portion of the south facing wall with a masonry wall; make sure that the existing foundation can be modified to support the additional weight.

The attached solar greenhouse is a retrofit device that can be used solely for supplemental space heating, but is most commonly used for both space heating and horticulture (see Figure 3-14).

If the greenhouse is to contribute heat directly to the house, some remodeling is generally necessary. A small greenhouse can also be directly attached to a window (window aperture enhancement greenhouses) as is illustrated in Figure 3-15.

Figure 3-13. U-Tube Window Box Collector



A window-mounted U-tube collector is an inexpensive and—if designed properly-effective retrofit.

Source Natural Convection Collectors, W Scott Morris, Solar Age, September, 1978

Figure 3-14. Solar Greenhouse Retrofit

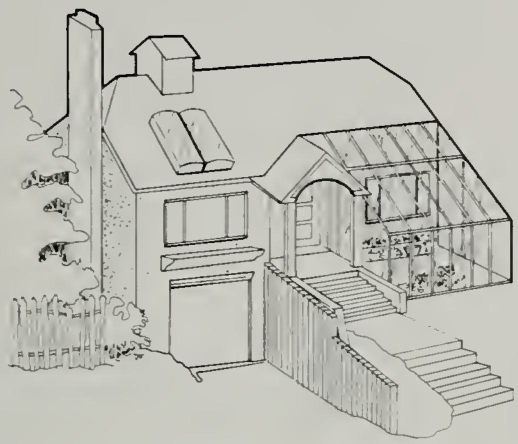


Figure 3-15. Window Greenhouse Apertures

Passive System Performance

A trombe wall system can be expected to convert incoming solar radiation to usable heat with about 35 percent efficiency. This efficiency is slightly higher than an active system which is generally 30 percent efficient. A direct gain system is even more efficient (40 percent) than a trombe wall. These efficiencies assume that night time heat loss is reduced to a minimum by effective insulation.

Currently there is insufficient information available regarding the effectiveness of most passive systems in the northern latitudes. The National Center for Appropriate Technology (NCAT) in Butte is now testing models of various passive systems to assess their effectiveness for space and water heating in Montana's climate. NCAT has determined that most passive systems in the northern climate need thermal shutters to prevent the loss of heat through the glazing and/or thermal wall during the night. See Appendix G for a technical discussion of NCAT's findings.

Edward Mazria has developed a computer program which simulates passive systems in the Pacific Northwest. His studies indicate that passive solar heating systems can supply on the average 50 percent of a building's winter space heating requirements and maintain relatively stable indoor air temperatures. The results of Mazria's computer simulated performance of a building designed with a south facing thermal storage wall is presented in Table 3-2. The building is well insulated with a space heat loss of 8.4 Btu/hr-ft². The thermal storage wall is a solid concrete mass one toot thick with double glazing on the exterior face. The exterior surface of the wall is painted black (solar absorption of 95 percent). The ratio of thermal wall to building floor is 1:2 and corresponds to a building 20'×40' with a 10'×40' solar wall. This system differs from a Trombe wall since thermocirculation vents are not used. In cold climates, wall vents with reverse flow controls can increase system performance up to 6 percent. In temperate cloudy climates, the increase in performance is slight since heat entering the building on mild and cloudy days is mainly by conduction through the solar wall.

Table 3-2. Thermal Storage Wall Performance Pacific Northwest Locations

	Degree Days/yr.	Percent Solar Heating
Eugene, Ore.	4357	59
Medford, Ore.	4401	71
Seattle, Wash.	4783	60
Spokane, Wash.	6456	61
Boise, Idaho	5663	71
Annette, Alaska	7096	66
Edmonton, Alberta	9830	55

The Economics of Passive Solar

Currently less information is available to assess the cost of passive systems than active systems. Since passive systems are part of a building's structure, pricing the passive components is difficult. However, a cost comparison between an active system and a trombe wall system can be made as follows: Assume a heating load of 37,064.5 Btu/hr for two homes in Great Falls, each system to provide a 70-80 percent solar fraction.

To calculate the cost of the active system, use the costs presented on p. 27.

collector cost = $15/ft² × 600 ft² =	$ 9,000
base cost =	2,500
total	$11,500

To calculate the cost of a trombe wall system compute the required area of glazing and multiply that by cost per square foot of the trombe wall. The glazing area can be calculated using Balcomb's rule #1 (page 37.) (For cold climates, such as Montana, this rule holds if the glazing is insulated at night). To employ rule # 1, 37,064.5 Btu/hr must be converted into Btu/hr -°F by dividing the design temperature difference of 80 degrees F.

$$\frac{37064.5 \text{ Btu/hr}}{80° \text{ F}} = \frac{463.31 \text{ Btu}}{\text{Hr-°F}}$$

To calculate the amount of glazing, multiply Btu/°F-hr by 2 sq. ft of glazing.

$$\text{Area} = \frac{463.31 \text{ Btu}}{\text{Hr-°F}} \times \frac{2 \text{ ft}^2}{\text{Btu/hr-°F}} = 927 \text{ ft}^2$$

The cost per square foot of the passive component can be obtained by reviewing costs of construction of existing houses with trombe walls. Shown below are estimates of the cost per square foot of the passive component of three houses using the trombe wall. These cost estimates are the total cost per square foot of the passive component minus the cost per square foot of conventional 2 × 6 stud wall construction.

Doug Kelbaugh home, Princeton, New Jersey	$16.67
Bruce Hunn home, Los Alamos, New Mexico	15.22
Charless Fowlkes home, Bozeman, Montana	14.00

The Fowlkes home is the only one of the three with movable insulation. The cost of this insulation is included in the $14.00/ft².

To calculate the cost of a trombe wall for the house in Great Falls, multiply 927 ft² × $14/ft²(=$12,978), which is about $1500 more than an active system furnishing the same solar fraction. However, the passive system requires little or no operation and maintenance costs and will last the lifetime of the home. Since parts of an active system probably will need replacing after twenty to thirty years of operation, passive systems appear to be more economical when priced over the life of the building.

A Note on Contractors and Architects

Contractors and/or architects can be employed in retrofit or new construction of passive and active systems. In their book **How to Buy Solar Heat Without Getting Burned** (Rodale Press, Emmaus, Pennsylvania, 1978), Malcolm Wells and Irwin Spetgang suggest that in order to have a successful relationship with a contractor it is advisable to:

- check his credentials
- make him bid competitively; then
- enter the contract in good faith, remembering this:
- don't overpay him during construction, and
- keep written records.

Check Them Out

Every reputable contractor will give out the names of his most recent customers. Check out his references. Something negative probably will be said about most contractors, so distinguish between significant complaints and insignificant ones. Try to get a sense of how the contractor performs on the important items and be flexible enough to live with some temporary frustrations on the others. It is also important to check out the contractor's credit rating; a local bank can help with this information.

Solicit Bids

Make sure when you solicit bids that all the bidders are bidding on the same or comparable solar systems. Some contractors are tied to specific manufacturers, so it is inadvisable to put out a bid on a specific brand of system. Rather, ask that each bidder meet specifications regarding materials and system performance.

Make it clear that the contractor is to do more than simply furnish — or install — the work; that he is to provide a complete, functioning, fully guaranteed system. Such a comprehensive statement written into the contract is recommended and is superior to a long and detailed specification from which a crucial clause may be inadvertantly omitted. Also, specify that the solar contractor himself must guarantee all workmanship and materials for a year.

A properly written contract can provide the homeowner with legal protection. Wells and Spetgang suggest obtaining the contract developed by the American Institute of Architects (AIA Document A107 — small construction contract, September 1966 edition from American Institue of Architects, 1735 New York Avenue N.W., Washington, D.C. 20006). They recommend that this model contract be compared to those presented by individual contractors.

Keep a complete record of major decisions, promises, and accomplishments during the period of construction. This log book can be a written source for the settlement of disputes. Let the contrator know that a log is being recorded and that he will be held accountable to the promises he has made. Most small construction jobs are completed so quickly that one payment at the end is all that's needed. Some solar installations, however, are so dependent upon other contractors or upon the progress of tricky alternation work that monthly progress payments become necessary. Traditionally, in construction contracts, after the amount of a monthly progress payment has been approved, a certain amount (usually 10 percent) is withheld from each payment, and the withheld sums are retained by the owner until the job is finished satisfactorily. The withheld money constitutes added protection in case the contractor fails to complete the work. On lengthy jobs, as the withheld funds accumulate, there is more certainty that the contractor will take care of the many minute details of construction which are often neglected.

Consulting an Architect

Most architects possess an extensive knowledge of the world of building — the expansion and contraction of materials, contracts, climatic influences, and design. Remember, however, that architects are not equipment designers. For the design of solar hardware, it is best to seek the professional help of a mechanical engineer. But if help is needed in relation to the space and appearance of a building, consult an architect. If the project is large enough, hire an architect and have him in turn engage, under his basic fee, the engineers needed to handle those basic skills (structural, mechanical, electrical) traditionally outside the architect's own specialities. In just an hour or two a well qualified architect can often suggest design changes or construction tips that will save far more than the amount of his fee, which can run from $15-$50 per hour. If the architect is aware of the life-cycle costs of materials and construction, he can probably save even more.

If possible, speak with several different architects and review several different designs. Inquire as to how much experience with solar design each architect or firm has. Check the architect's credentials. Does he or she belong to the American Institute of Architects (AIA)? Membership in the AIA does not guarantee that the architect is a good one, but it does mean that he has a good professional standing and sound architectural training.

Once an architect has been chosen, make sure you understand in advance how the solar home will work and what lifestyle adjustments, if any, may be necessary. Ask questions about the design and don't let any features over which there are serious doubts go into the final design. Finally, make sure the architect and builder are agreed on all of the details of the house. Have the builder and architect meet each other before contracts are signed with either of them.

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Books

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Natural Solar Architecture: A Passive Primer, by David Wright, 1978. Wright's aim as he states in his Introduction, is to "help fulfill the need for prerequisite knowledge of passive concepts for students, architects, builders, home planners survivalists prior to the undertaking of the ultimate logical process of designing a climatically oriented structure." This book is a very thorough and integrated treatise on the subject of passive solar. $7.95 from Van Nostrand Reinhold Company, 135 West 50th Street, New York, NY 10020.

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CHAPTER IV

WIND ENERGY SYSTEMS

Introduction

Wind energy can be harnessed to produce electrical, mechanical and heat energy. Wind systems which produce electricity (wind electric conversion systems - WECS) dotted Montana's prairie country during the 1930's and 40's. Many of these systems were Jacobs wind chargers manufactured in Montana. Most fell into disrepair when low-cost electricity became available through the rural electrical co-ops.

Today there is only a small number of wind electric systems extracting energy from Montana's winds. The majority of wind machines currently operating provide mechanical energy for water pumping.

At the present time in Montana, it is not economically feasible or practical to meet space-heating requirements with a small wind electric system. But small scale (machines producing up to 600 kw) systems can be used effectively to meet the electric demand (appliances and lights) of a residence or small business.

The focus in this chapter is on small-scale WECS: The technical characteristics of small scale systems, determining the wind resource, determining the power requirements, assessing the cost and energy output of small scale systems, selecting the site, environmental hazards to wind systems and ascertaining the legal barriers, if any, are discussed.

A Survey of the Technical Characteristics of Wind Electric Conversion Systems

There are four major components of wind systems: the wind machine; the tower which supports the machine; the storage system of batteries or connection with the utility power line; and electrical devices such as inverters, voltage regulators and automatic switches.

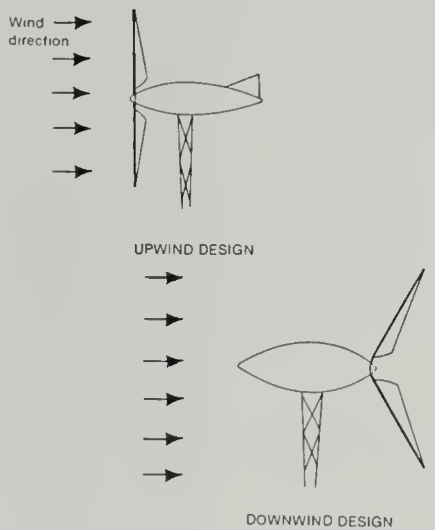
> *"When we talk about wind plants and hydroelectric systems we are talking about 'power to the people' in a much more meaningful way than most folks realize."*
>
> William Delp
> Noxon, Montana

Wind Machines

Wind machines are usually classified according to their axis of rotation relative to the direction of the wind. In this section, horizontal axis and vertical axis rotors are discussed.

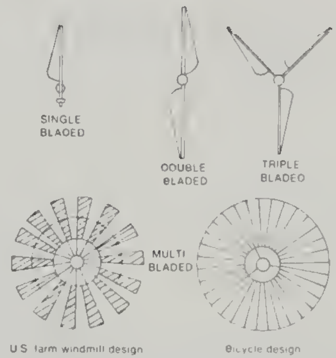
Horizontal axis machines are machines where the rotational shaft which transmits the mechanical energy of the blades to an electric generator is parallel to the direction of the wind. The blades of a horizontal-axis wind machine face into the wind (upwind machine) or behind the tower (downwind machine). Figure 4-1 illustrates these two types of horizontal-axis machines.

Figure 4-1. Upwind and Downwind Horizontal-Axis Rotor Designs



SOURCE **Fundamentals of Wind Energy** Nicholas P Cheremisinoff, Ann Arbor Science Publishers, Michigan, 1978

Figure 4-2. Typical Blade Configurations for Horizontal-Axis Rotors



SOURCE **Fundamentals of Wind Energy**, Nicholas P Cheremisinoff, Ann Arbor Science Publishers, Michigan, 1978

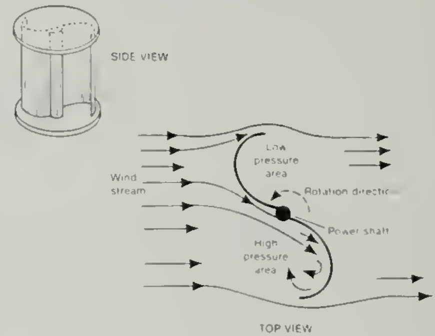
Horizontal-axis machines are designed with a varied number of blades ranging from one-bladed units equipped with a counterweight to multiblade systems having 50 or more blades. Figure 4-2 shows several blade configurations.

Most horizontal-axis machines are yaw-activated which means that they change position depending on the wind direction.

In vertical-axis machines, the axis of rotation is at right angles with respect to both the wind and the earth's surface. The Savonius rotor is currently the most common design (see Figure 4-3). These machines use S-shaped blades which catch the wind to spin the rotor. A disadvantage of the Savonius machine is that relatively high starting torques are required.

Another disadvantage is that the Savonius design has limited rotational speed, since the wind-catching elements are returned against the wind, thereby diminishing the machine's acceleration.

Figure 4-3. Savonious Rotor Design



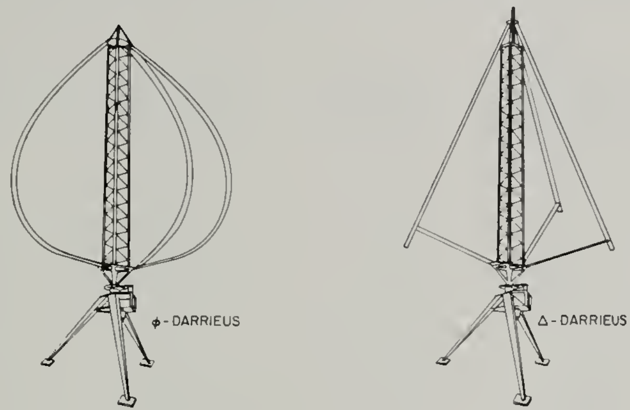
The Savonius S-shaped design has the disadvantage of returning wind-catching elements against the wind

SOURCE **Fundamentals of Wind Energy** Nicholas P Cheremisinoff, Ann Arbor Science Publishers, Michigan, 1978

One vertical axis design is the Darrieus-type rotor (see Figure 4-4). Unlike the Savonius, the Darrieus type machine has two or three thin, air-foil blades. This blade configuration requires only low wind speed to start the rotor spinning. The Darrieus design may be the most promising of all wind machines available for electric power generation because:

- the need for yaw control is eliminated due to its vertical symmetry;
- only a simple tower structure is required reducing construction costs and design considerations;
- gearboxes and generators can be mounted at ground level rather than at the top of the tower which is the case with horizontal axis machines; and
- the simplicity of blade design and the thinness of the blade reduces blade fabrication cost.

Figure 4-4. Darrieus-Type Rotor Designs



SOURCE: **Fundamentals of Wind Energy**, Nicholas P Cheremisinoff, Ann Arbor Science Publishers, Michigan, 1978

Although the Darrieus seems to be the superior design for electricity generation, because it is a new design only a few models are commercially available compared to over 25 commercially available, horizontal axis wind machines.

Towers

A tower is the supporting structure of a wind machine. A tower must support the weight of the wind machine and withstand forces exerted by the wind itself. The tower is used to place the wind rotor in a good wind location, away from the drag and turbulence effects induced by ground obstructions. Commercially available towers are usually fabricated to withstand all but hurricane force winds. These towers are fabricted with steel and/or aluminum in a lattice structure or tubular column. Towers are designed to be either free standing or guyed. Small wind machines can be erected using ropes, and winches, but larger machines may require expensive cranes and other special tools.

Storage Systems

An electrical generating wind system converts the kinetic energy of the wind into mechanical energy and then into electricity. The blades catch the wind and produce rotational motion in the center shaft of the wind machine which is connected to an electrical generator (or alternator in many cases) which produces the electricity. As with water pumped by a farm windmill, the energy provided by a wind generator can be used as it is generated, or stored for later use. Since wind energy is not always available, excess energy must be stored for the system to be effective.

Long term hourly wind observations have been used to show that a totally independent and reliable wind energy system would require an impractically large storage capacity. A cost-effective balance between reliability and size of storage must be ascertained for each system.

The storage of wind-generated electricity can be accomplished with conventional storage batteries or by using a synchronous inverter with the consent of the utility company. The storage battery has been used with wind systems for many years to provide electricity when winds are calm. A set or bank of batteries is used to store power for as much as three days. This kind of storage is primarily used in areas where commercial utility power is not available.

A device known as the synchronous inverter has been used in place of conventional storage batteries since 1975. The inverter electronically mixes power from the wind machine and the utility line. If the wind machine is producing excess power, the inverter will feed the excess into the utility line. Conversely, if the wind machine is not producing enough energy to satisfy the user, the inverter will draw additional electricity from the utility line. Two meters are usually required with a synchronous inverter: one to register the amount of electricity drawn from the utility line and another to register the amount fed back into the line from the wind machine.

Of course, the utility must agree to allow the hook up of the inverter. Utility companies have indicated concern with the potential safety and technical hazards which an inverter might cause. There is the danger that a utility lineman who has disconnected the power at his end in order to make repairs could be shocked or electrocuted by electricity discharged into the line at the other end by a wind machine. Utilities are also concerned that the wave form of wind generated electricity will not correspond to the wave form of utility electricity. This could result in damage to certain sensitive electronic equipment such as stereos and televisions. Another technical hazard posed by synchronous inversion is possible damage to utility transformers if the excess electricity is delivered backwards into the utility line.

Electrical Devices — The Inverter

Electrical devices transform and carry the current to the point of use. The most important of these devices is the inverter. Inverters convert the direct current from the storage batteries into alternating current required by modern appliances and lights. Many models of inverters are designed to sense changes in loads and provide protection against overloading or complete drainage of the batteries.

Determining the Wind Resource

Knowledge of average wind speed is essential in siting a machine. Average annual wind speed information for Montana's major cities is presented in Table 4-1. However, individual sites may receive considerably more or less wind than the velocities indicated in the table.

Winds at a particular site may be recorded and analyzed by any one of three methods described in Table 4-2. Once the winds are recorded, the expected power output of a wind system may be computed.

The first method requires only a knowledge of the average annual wind speed at a site. This information, which can be obtained from nearby weather stations, is likely to be accurate if both locations are within a few miles of each other and if both are in the same large area of flat terrain (e.g., a large plateau, or a large basin). But if the terrain at the site differs greatly from the terrain at the weather station, the approach will not be very accurate.

The second method is more accurate than the first. An odometer-type wind recorder, which measures the miles of wind passing by the site (the wind run), should be used for a minimum of three months to collect onsite data, preferably during the three most windy months.

Table 4-1. Annual Wind Information for Major Montana Cities

	(1) Average Yearly Wind Speed (mph)	(2) Average Total Power in the Wind (watts m^{-2})	(3) Theoretically Extractable Power in the Wind (watts m^{-2})	(4) Average Power Available to a Windmill of 70% Efficiency (watts m^{-2})
			(.593 × (2))	(.70 × (3))
Billings	11.65	124.9	74.1	51.9
Cut Bank	12.6	89.3	53.0	37.1
Dillon	9.1	33.6	19.9	14.0
Great Falls	12.4	190.4	112.9	79.0
Havre	10.4	121.5	77.0	50.4
Helena	7.9	68.2	40.4	28.3
Kalispell	6.9	54.5	32.3	27.6
Lewistown	10.1	46.0	27.3	19.1
Livingston	14.1	305.9	181.4	127.0
Miles City	10.8	117.5	69.7	48.8
Missoula	6.5	44.7	26.5	18.6

SOURCE: Robert Warrington, Mechanical Engineering Department, Montana State University, 1978.

Table 4.2 Various Approaches to Site Analysis

Method	Approach	Advantages	Disadvantages
1	Use only mean annual speed from a nearby station; determine annual power output.	Little time or expense required for collecting data. If used properly, can be highly accurate.	Only works well in large area of flat terrain where average annual wind speeds are 10 mph or greater.
2	Make limited onsite wind measurements, establish rough correlation with nearby station, then compute power output.	More accurate than first method. Works well in all but very hilly or mountainous terrain.	Requires time to collect data. Data period must represent typical wind conditions. Added cost of wind recorders. Works poorly in mountains.
3	Collect wind data for the site and analyze it to obtain annual power output.	Most accurate method. Works in all types of terrain.	Requires a year of data collection. Added costs of wind recorders. Data period must represent typical wind conditions.

SOURCE. **A Siting Handbook for Small Wind Energy Conversion Systems**, Battelle, Pacific Northwest Labratory, Richland, Washington, 1978

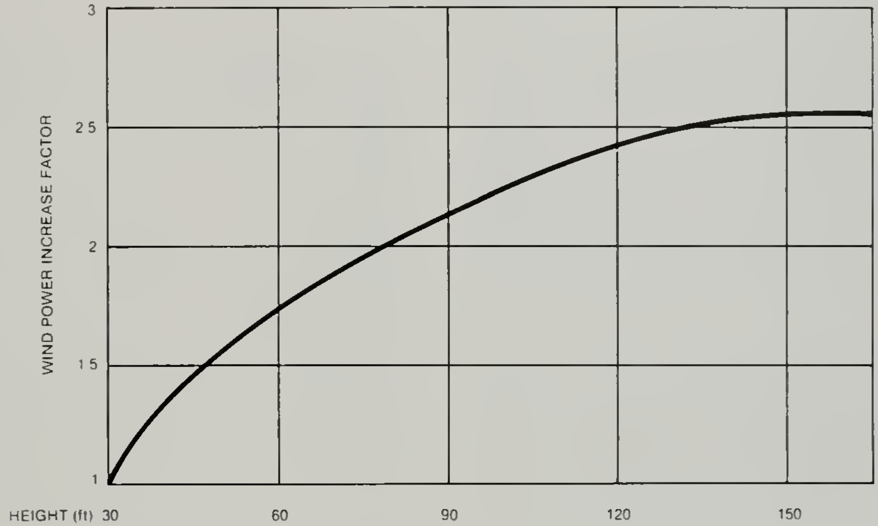
The third method is the only reliable one for estimating power output in complex terrain. Mountains, valleys, and other topographical features cause the wind to vary from one location to another. For instance, in mountainous terrain the mean annual wind velocity may increase by 20 percent, yielding a power increase of up to 75 percent. Therefore, an entire year of data should be collected at candidate sites in complex terrain.

Simple odometer-type devices to measure wind velocity can be purchased for about $100 or possibly can be rented from dealers. By recording the miles of wind monthly and dividing miles by the number of hours in the month, the monthly average wind speeds (and in the same manner, the annual average wind speed) can be computed and average output power estimated.

Aside from the geographical location and topographical features of the site, wind resource varies with height. Wind velocity increases with height above the ground as shown in Figure 4-5.

The higher the wind machine is placed the more power it can extract from the available wind. In addition, the power output of the machine goes up as the square of the propeller diameter, until the rated capacity of the generator is attained. (See Table 4-3).

Figure 4-5. Effect of Height on Windpower



SOURCE Montana Conservation Plan Ecotype Group, Seattle, Washington, 1977

Table 4.3 Shaft Horsepower as a Function of Prop Diameter and Wind Velocity (Table applies to all 75% efficient wind machines)

Prop Diameter (feet)	Wind Velocity (mph) 10	20	30
25	1.5 hp	12 hp	40.5 hp
50	6.0 hp	48 hp	162 hp
100	24 hp	190 hp	638 hp
300	212 hp	1700 hp	5728 hp

SOURCE. Robert Warrington, Mechanical Engineering Department, Montana State University, Bozeman, Montana, 1978

Determining Power Requirements

The rated generating capacity of a wind machine is the total amount of electric power (usually in watts) that the machine can produce at any instant. A wind machine rated at 5000 watts (5 kw) capacity can supply a demand of 5000 watts at any given moment provided that the actual wind velocity equals or exceeds the system's rated wind speed — the wind speed required for the wind system to produce its rated output.

In order to choose an appropriate wind electric system, the average and peak power loads which will be demanded of the wind system must be computed.

The electric demand of a non-electrically heated residence or small business usually will consist of appliances and lights. Rarely will all appliances and lights be on at the same time so that the average electric load will be considerably less than the peak or total load requirements. A wind electric system matched to average load requirements will need less generating capacity and will be more efficient than one designed to meet peak load requirements. Table 4-4 lists the typical power requirements for a number of electrical appliances. The peak load is determined by adding the "rated" amounts of all appliances and lights.

In addition to determining the average and peak load demand an estimate of monthly electric consumption in kilowatt hours of each appliance is helpful. The total monthly consumption of electricity will influence the size of storage for the wind machine. The basic procedure to determine total monthly electrical consumption is to multiply the watts of each appliance times its use in hours per month and then total the kwh consumption for all appliances and lights. The wattage figures given in Table 4-4 are averages; when possible, use the ratings that are given on the appliances themselves. Sometimes the nameplates on the appliances give the current drawn rather than the watts; for example, "2A" would mean 2 amps. To calculate power, multiply the current by 120 volts (2 amps × 120 volts = 240 watts). Another source of power ratings for appliances is department store catalogues. The typical Montana household uses about 400-500 kwh/month for lighting and appliances. (If a home is electrically heated it can use as much as 3000 to 4000 kwh per month).

Table 4.4 Approximate Rated Watts and Monthly KWH Consumption of Household Appliances

Household Appliance	Rated Watts	Monthly KWH
Air conditioner (window)	1300	105
Bed covering	170	12
Broiler	1375	8
Clock	2	1.5
Clothes dryer	4800	80
Coffee maker	850	8
Cooker (egg)	500	1
Deep fat fryer	1380	6
Dehumidifier	240	32
Dishwasher	1190	28
Electrostatic cleaner	60	22
Fan (attic)	375	26
Fan (circulating)	85	3
Fan (furnace)	270	30
Fan (roll-about)	205	9
Fan (window)	190	12
Floor polisher	315	1
Food blender	290	1
Food freezer	300	76
Food mixer	125	1
Food waste disposer	420	2
Fruit juicer	100	0.5
Frying pan	1170	16
Germicidal lamp	20	11
Grill (sandwich)	1050	2.5
Hair dryer	300	0.5
Heat lamp (infrared)	250	1
Heat pump	9600	—
Heater (radiant)	1300	13
Heating pad	60	1
Hot plate	1250	8
Humidifier	70	12
Incinerator	605	55
Iron (hand)	1050	11
Iron (mangle)	1525	13

Household Appliances	Rated Watts	Monthly KWH
Oil burner or stoker	260	31
Radio	80	7.5
Radio-phonograph	105	9
Range	11,720	102
Roaster	1345	17
Refrigerator	235	38
Refrigerator-freezer	330	70.5
Refrigerator-freezer (frostless)	425	135
Sewing machine	75	1
Shaver	15	0.2
Sun lamp	290	1
Television	255	29
Television (color)	300	37.5
Toaster	1100	3
Vacuum cleaner	540	3
Vibrator	40	0.2
Waffle iron	1080	2
Washing machine (automatic)	375	5.5
Washing machine (nonautomatic)	280	4
Water heater (standard)	3000	340
Water heater (quick recovery)	4500	373
Water pump	335	17

In the Shop	Motor Size (horsepower)	Rated Watts
Bandsaw	0.50	660
Drill (portable, 3/8")	0.20	264
(press)	0.50	660
Lathe (12-inch)	0.33	660
Router	0.75	720
Sander (orbital)	0.20	300
(polisher)	1.50	1080
Saw (circular)	1.66	1080
(saber)	0.25	288
(table)	1.60	950

SOURCE Other Homes and Garbage: Designs for Self-Sufficient System, Jim Leckie et al., Sierra Club Books, San Francisco, 1975

Cost and Energy Output for Small Scale Wind Systems

A preliminary feasibility study assessing the economic viability of a wind system is essential to determine if a wind machine is practical on a site. The cost of the system can be easily obtained, but it is cost per kilowatt hour of wind generated electricity which is the most useful index cost. The cost per kwh can be calculated from the total system cost and the expected energy output of the system. Detailed analyses are required for these calculations and depend principally upon the amount of wind energy available at the site and the operating characteristics of the wind system.

To determine the available wind energy, the wind speed frequency distribution is required. This distribution is a breakdown of the frequency of occurrence of wind speeds in various wind speed ranges. Determining the long term frequency distribution at a prospective site can be a lengthy and expensive process. Fortunately, an estimate can be made on the basis of the annual mean wind speed. This estimate is adequate for small scale wind machines. This procedure has been presented on page 48.

The operating characteristic of a wind plant is the relation between the level of power output and the wind speed. A typical power characteristic curve is shown for a Dunlite wind plant in Figure 4-6. A reading of the graph shows that the wind plant produces no power for wind speeds below about 7 mph. At about 7 to 8 mph, the "cut-in wind speed" for this wind plant, some power is produced. As the wind speed continues to increase above 8 mph, the level of power produced increases rapidly due to the cubic relationship between wind speed and available wind power. At the "rated wind speed' of about 24 mph, the wind plant is producing 100 percent of the rated capacity of the alternator. For higher wind speeds, the blade pitch is controlled to spill excess wind and provide a constant power level. Most wind plants are designed to stop operating completely when the winds become too high to prevent damage to the wind plant or the tower. This maximum operating wind speed is often referred to as the "furling" or "cut-out" speed.

Extensive computer modeling of a number of small wind plants has been completed by J. B. Obermeier and published in "Wind Electric Power Generation in Montana." Copies can be obtained from the Montana State University Library. Obermeier collected hourly wind speed data over a five year period for ten Montana locations. Figures 4-6 through 4-9 display the annual average useful energy output of four small wind plants as a function of the annual mean wind speed. The four case examples presented include two low voltage wind plants in battery charging systems and two 110 volt wind plants in synchronous inversion systems. In all cases, the curve for useful energy produced is based upon the results of Obermeier's work. The power characteristic used for each wind plant, details of the system configuration, costs and economic variables assumed for each case also are presented in the figures.

For example, consider a potential user who has a cabin located in a remote mountain region. Assume that the annual average wind speed is 8½ mph at this location and that the user's electric needs are fairly low compared to an average residential electric user. Figure 4-7 shows that a 1 kw Sencenbaugh wind plant with storage batteries could provide about 1000 kwh annually or an average of 83 kwh per month. Of course, the amount would vary depending on the seasonal variations in the wind. For this wind system, the owner could expect to pay around $5,407 for purchase and installation. Under the economic conditions stated in Figure 4-7, this user could expect to be paying about $.24/kwh for the useful electricity produced over the 20 year life of the system compared to $.025/kwh for utility electricity.

As a second example, consider a potential user who already has electric utility service in the plains north of Great Falls. Since the thirty year mean wind speed at the Great Falls Airport is 13.1 mph, this should provide a good estimate of the mean speed at the selected site. Assuming that a rebuilt 3 kw Jacobs could be purchased for $2,500 the total system cost would run about $5,000 including a guyed tower and synchronous inverter. Figure 4-9 shows that 4600 kwh annually (383 kwh monthly), or about 60 percent of the total electric requirements can be expected from this wind machine. With the economic assumptions stated in Figure 4-9, the effective cost of this wind generated electricity would be about $.12/kwh. The total energy produced by the plant (the dashed line in the graph) at 13 mph is about 9000 kwh annually. Thus, the difference between this 9000 kwh and the useful energy to the load (4600 kwh) yields 4400 kwh annually which is fed back into the power grid. The previously mentioned costs did not account for any payback by the utility for the energy put into the grid.

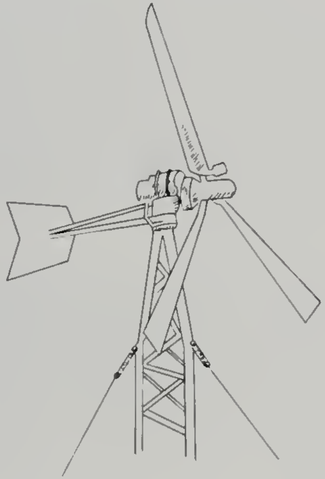
Currently, the cost of electricity generated on a kwh basis from small-scale wind systems is much greater than the electricity purchased from utility systems. However, as the cost of utility electricity increases and as the cost of wind technology decreases due to mass production, wind generated electricity may become economically attractive.

Site Selection

A wind machine should be at least 40 feet above the ground and at least 15 to 20 feet higher than any obstructions. An appropriate site for a small scale wind machine should be near enough to the building to minimize power loss in the connecting wires, yet far enough away from obstructions such as other buildings and trees. Obstructions which are higher than the windplant can disturb the wind for several hundred yards behind the obstacle and perhaps even 50 to 100 yards in front of the obstacle.

Attention must be paid to potential safety and operating problems when siting the wind machine. The machine should be sited at a sufficient distance from buildings and activity areas to prevent injury from tower and blade failure, and hazards associated with electric

Figure 4-6.
Characteristics of Dunlite 2000 Wind Plant



Wind Plant: Dunlite 2000

Rated Output: 2 kw at 24 mph

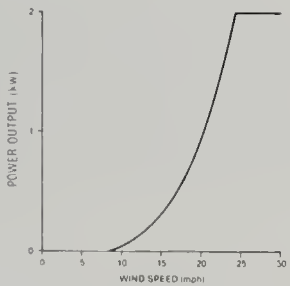
Swept Diameter: 13 ft.

System Description:
Dunlite 2000 wind plant, 110 v DC. Gemini 4 kw synchronous inverter. Gemini adapter. Lightning protection. Guyed tower, 40 ft.

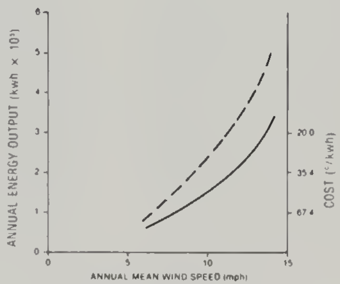
Electrical Load: 650 kwh/mo.

Economic Variables:

First Cost	$6530
Installation Cost	$ 653
Maintenance Cost/yr	$ 98
Annual Cost	$ 699
Economic Life	20 yr
Rate of Return	5½ %



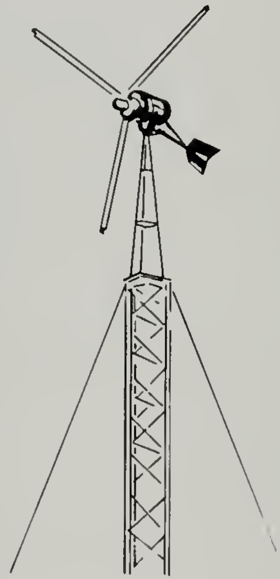
POWER CHARACTERISTIC CURVE



ENERGY COSTS AND
ANNUAL ENERGY OUTPUTS

SOURCE J L Obermeier, Great Falls, Montana, 1978

Figure 4-7.
Characteristics of Sencenbaugh Wind Plant



Wind Plant: Sencenbaugh

Rated Output: 1 kw at 20 mph

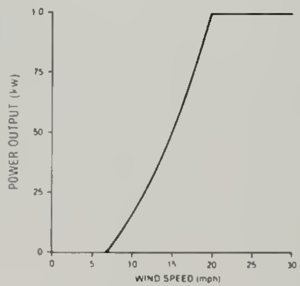
Swept Diameter: 8 ft.

System Description:
Sencenbaugh wind plant, 12 v DC. Lightning protection. DC to AC inverter. Guyed tower, 40 ft. Battery storage 1326 amp hours.

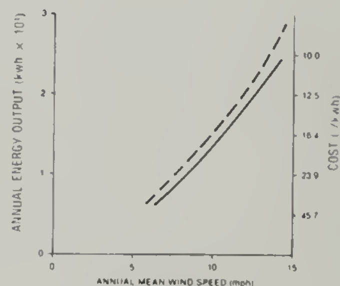
Electrical Load: 271 kwh/mo.

Economic Variables:

First Cost	$4915
Installation Cost	$ 492
Maintenance Cost/yr	$ 74
Annual Cost	$ 250
Economic Life	20 yr
Rate of Return	5½ %



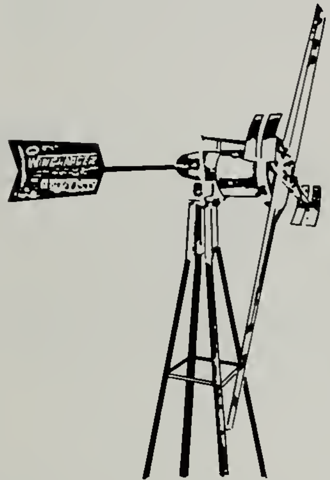
POWER CHARACTERISTIC CURVE



ENERGY COSTS AND
ANNUAL ENERGY OUTPUTS

SOURCE J L Obermeier, Great Falls, Montana, 1978

Figure 4-8.
Characteristics of Windcharger Battery Storage System



Wind Plant: Windcharger

Rated Output: 210 watts at 23 mph

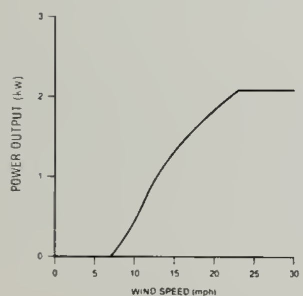
Swept Diameter: 6 ft.

System Description:
Windcharger 12 v DC with 10 ft. tower stub. DC to AC inverter. Battery storage capacity 440 amp hours.

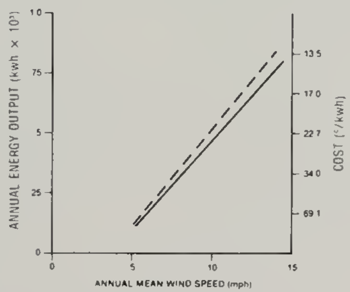
Electric Load: 271 kwh/mo.

Economic Variables:

First Cost	$915
Installation Cost	$ 92
Maintenance Cost/yr	$ 14
Annual Cost	$114
Economic Life	20 yr
Rate of Return	5½%



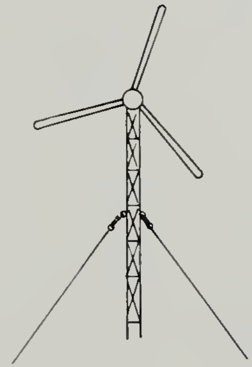
POWER CHARACTERISTIC CURVE



ENERGY COSTS AND ANNUAL ENERGY OUTPUTS

SOURCE: J. L. Obermeier, Great Falls, Montana, 1978

Figure 4-9.
Characteristics of Jacobs WE3000 Wind Plant



Wind Plant: Jacobs WE3000

Rated Output: 3 kw at 20 mph

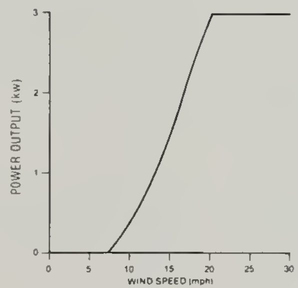
Swept Diameter: 16 ft.

System Description:
Jacobs WE3000 wind plant, 110 v DC. Gemini 4 kw synchronous inverter. Guyed tower, 40 ft.

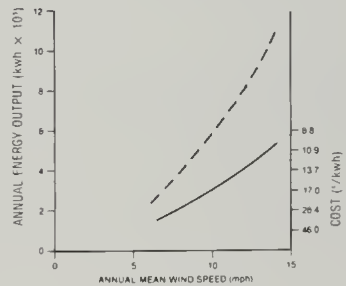
Electrical Load: 650 kwh/mo.

Economic Variables:

First Cost	$5010
Installation Cost	$ 501
Maintenance Cost/yr	$ 75
Annual Cost	$ 536
Economic Life	20 yr
Rate of Return	5½%



POWER CHARACTERISTIC CURVE



ENERGY COSTS AND ANNUAL ENERGY OUTPUTS

SOURCE J L Obermeier, Great Falls, Montana, 1978

transmission equipment. The hazardous zone for tower failure is a circular area with a maximum radius roughly equal to the height of the tower plus the radius of the disc formed by the blades. Blade throw would affect a much larger area. The hazardous areas for electric transmission equipment extend from the wind machine to the building along the transmission corridor. The potential causes of these failures include mechanical stress due to wind shear, cataclysmic weather events such as severe storms or tornados and rotational forces of the machine itself. The wind machine should also be sited to minimize noise from its operation.

Environmental Hazards To Wind Energy Systems

Once they are installed and operating, wind systems may be subject to the following hazards:

Air Turbulence is caused by rapid changes in the speed and/or direction of the wind. The turbulence most harmful to wind machines is the type produced when wind flows over a rough surface or barrier creating small-scale rapid fluctuations in the wind. This turbulence causes a decrease in harnessable power in a wind machine. Also, the vibrations and unequal loading on the wind machine may eventually weaken and damage it.

Wind shear may also pose a hazard to wind machines. Wind shear is a large change in the speed and direction of the wind over a small distance. If a large change occurs over a distance less than or equal to the diameter of the rotor disc (the area swept by the rotor blade), then unequal forces will be acting on the blade. Generally, the longer the blade, the more susceptible the installation is to shear hazards. Wind shear can be a hazard to any wind machine which is too near the ground, a canyon wall, a steep mountainside, or the top of a flat-topped ridge.

Extreme winds can damage both the machine and its supporting tower. The blades are vulnerable if the protection systems designed into the wind machine fail. Towers should be designed to survive all wind speeds that normally occur in an area. Extreme wind speeds should be obtained from nearby weather stations if the wind machine is to be located in or near the mountains.

Thunderstorms may bring high winds, hail and lightning and possibly tornados. A wind installation should be protected from lightning; hail can damage both the wind mill and its tower.

Icing on the blades, tower and transmission lines can cause hazards or reduce the efficiency of the WECS. There are two types of icing: rime ice and glaze ice. Rime ice forms from frost or freezing fog rather than from rain; it occurs mainly at higher elevations and is drier, less dense, and less hazardous than glaze ice. Glaze icing forms from freezing rain and occurs most frequently in valleys, basins, and other low elevations. When rain falls through a subfreezing layer of air at the ground, the drops freeze on contact with the surface. Freezing precipitation can rapidly accumulate on a cold surface to thicknesses of more than two inches. In almost all areas of Montana there is no real threat of substantial icing, but icing should be taken into consideration.

Heavy Snow poses three hazards to wind installations: service and maintenance can be made difficult because of excessive snow depths; heavy snowfalls may damage parts of the turbine; and blowing snow may infiltrate the machine parts and cause breakage from freezing and thawing

Flood and slides are hazards that should be taken into account. If an ideal wind site is on the floodplain, the tower should be built to withstand flood conditions. Wherever a wind machine is sited, the stability of the soil should be tested and the potential for earth slides investigated.

Extreme temperatures will affect most wind machines. Lubricants may freeze in very cold temperatures and cause rapid wear on all moving parts. Many paints and lubricants deteriorate in high temperatures.

Blowing dust will damage the wind system if it penetrates moving parts such as the gears and turning shafts. Blowing dust can also cause accelerated deterioration to paints and exposed surfaces, especially the blades.

Legal Barriers

Installation of a wind system in a town or city may pose legal problems. Building codes and zoning are the two areas of law which most affect installation of WECS in an urban setting Building codes may restrict the height of structures on certain types of property and zoning ordinances can prevent the installation of wind machines because of their proximity to property lines and the noise they generate. Legal restrictions should be investigated. If existing law prevents installation of a wind machine, variances sometimes can be obtained from the proper authorities. Also, since a wind machine can be a public hazard, liability insurance should be obtained as the wind system may or may not be covered by home owner insurance.

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Windletter Available only with membership in AWEA. This newsletter documents AWEA affairs and, as of the February 1978 issue, is covering topics of current interest to technical people and others involved in wind energy in the United States. Brief status reports are given on the latest wind energy developments. These include technical research summaries, legislative actions, requests for proposals and application surveys. From The American Wind Energy Association, 55468 CR 31, Bristol, IN 46507.

Wind Power Digest This quarterly magazine is committed to popularizing and promoting wind power as a viable energy source. It is written in an easy-to-understand format, usually in the form of specific case studies. It attempts to reach a lay and professional audience. Articles describe the machinery available, owner-operator experiences and a few technical research projects. It is generously supplied with photographs, sketches, charts and tables. From SWES, 54468 CR 31, Bristol, IN 46507.

Wind Technology Journal This is the technical journal of the American Wind Energy Association. A quarterly initiated in Spring 1977, it contains scientific papers on the latest research on wind energy in the United States. From AWES, 54468 CR 31, Bristol, IN 46507.

CHAPTER V

WATER ENERGY SYSTEMS

Introduction

Water power application is one of the world's oldest energy technologies. The solar evaporation and condensation cycle creates a renewable flow of energy that can be tapped in several ways. Large, simple, low-speed water wheels have been used throughout history to provide mechanical energy for such things as wood cutting and milling of agricultural products. In the last few years high-speed water turbines have come into use.

In Montana there are many streams and waterfalls, particularly in the western part of the state where the rainfall and stream gradients are greatest. Some communities and individuals could harness the power from this falling water to supply their individual electrical demands. Some mechanical energy needs could also be met with simple water wheels.

A slow, meandering stream, having a cross-section of only a few square feet gives up more energy in a fall of several feet than is needed to power the electrical appliances of the average household. Estimating the energy that a stream can supply and methods by which that energy can be captured, stored and converted into electricity are discussed in this chapter.

> *"We are still expanding our rate of consumption of gross energy, but since we are feeding a higher and higher percentage back into the energy-seeking process, we are decreasing our net energy production."*
>
> Howard T. Odum

Calculating the Potential Energy of a Stream

A stream contains two forms of energy. By virtue of its velocity it contains kinetic energy, and by virtue of its elevation it contains potential energy. The kinetic energy in most streams is not great enough to be useful; it is the potential energy between two sites of differing elevations that can be harnessed effectively. This difference in elevation is known as the "head." An elevation difference of 60 feet or less is called low head (a head of 10 feet or less is a very low head); a difference of 60 feet or more is called a high head.

The amount of power obtainable from a stream is proportional to the rate at which the water flows and the vertical distance through which the water drops. The basic formula is:

$$P = \frac{QHe}{11.8} \qquad Q = AV$$

where P is the power obtained from the stream in kilowatts; Q is the flow of water in cubic feet per second (cfs); A is the average cross-sectional area of the stream in square feet; V is the average velocity of the stream in feet per second; H is the height the water falls (head) in feet; 11.8 is a constant which accounts for the density of water and the conversion from ft-lb/sec to kw; and e is the overall conversion efficiency. The conversion is on the order of 0.5 to 0.7 and accounts for the various losses which occur during the conversion to electricity.

It is important to know not only the average stream flows, but also the expected minimum and maximum flows. A minimum low estimate is necessary to insure that enough power can be generated; a maximum flow estimate is necessary to insure that the structure will be safely designed for times of peak flooding. These estimates can be obtained for the major streams from the U.S. Geologic Survey Office in Helena, which has stream flow records for the state.

To estimate the cross-sectional area of a stream at a given site, measure the depth of the water at a number of equally spaced points across the stream and calculate their average. The number of points needed depends on the irregularity of the cross-section and width of the stream, but five or ten should do. The cross-sectional area is then determined by multiplying the width of the stream (where you measured the depth) times the average depth.

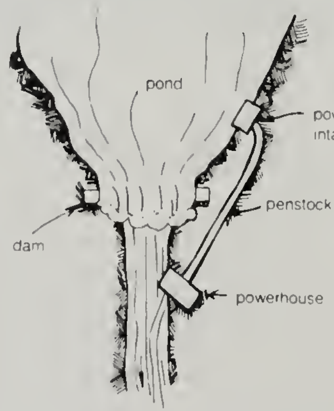
To estimate the velocity, first measure the distance between two fixed points along the length of the stream where the cross-sectional area measurements were made. Then toss a float into the center of the stream and measure the length of time required for it to travel between the two fixed markers. Dividing the distance by the time results in the average velocity of the float. But since the stream itself encounters drag along its sides, surface and bottom, the float will travel a bit faster than the average velocity of the stream. By multiplying the float velocity by a correctional factor of about 0.85, an estimate of average stream velocity is obtained. This method is useful for design purposes only if the minimum, maximum and average annual velocities are determined.

Harnessing Water Energy

A basic method for tapping the potential energy of water is to divert some of the water from a site upstream, transport it along an elevated conduit, and then let it fall through a waterwheel or hydraulic turbine located at a lower elevation downstream. The turbine (or waterwheel) turns a generator which produces electricity; the water then returns to the stream. This method can be applied through the simple diversion of the flow into a conduit, if a stable head and sufficient flow can be obtained in this way. If not, a dam with a sufficient reservoir of water is necessary to assure both a stable head and an adequate flow. A spillway must be constructed to allow the stream to overflow the dam when the pond is full, thus protecting the dam from overtopping floods.

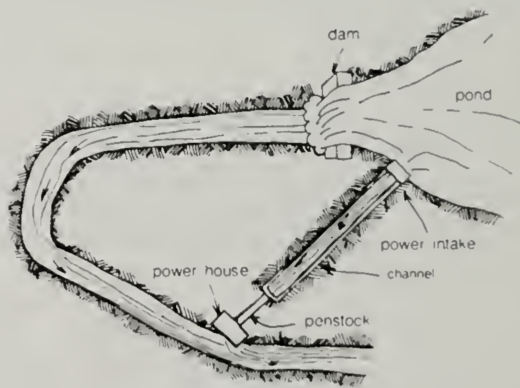
Water can be transported from a dam to a waterwheel or a turbine in an open channel and/or in a pressure conduit called a penstock. The powerhouse (where the electricity is generated) may be either next to the dam as shown in Figure 5-1 or further downstream as show in Figure 5-2.

Figure 5-1. Powerhouse Below Dam



SOURCE **Other Homes and Garbage: Designs for Self Sufficiant System**, Jim Leckie, et al., Sierra Club Books, San Francisco, 1975

Figure 5-2. Powerhouse Further Downstream



SOURCE **Other Homes and Garbage: Designs for Self-Sufficient System**, Jim Leckie, et al., Sierra Club Books, San Francisco, 1975

Some low head and high head systems do not require a dam and are particularly appropriate for residential application in Western Montana where the rainfall is heavy and there are mountains which provide high potential head. These systems divert a portion of the streamflow through steel pipes to an impulse turbine and then return the water to the stream. An impulse turbine operates most effectively with at least a fifty foot head, but can be run with as little as a ten foot head. High and low head systems without dams can provide peak power on demand from the battery storage only. However, dams can provide peak power generation on demand by increasing the flow to its maximum.

With a high head impulse turbine, a portion of the potential energy of the head is lost to friction between the water and the pipe. The greater the diameter of the pipe, the less the friction loss. For example, a 2½'' diameter pipe for a high head installation will have a friction loss equivalent to about one foot of head for every 24 linear feet. Pipe diameter also influences the generating capacity of the turbine. For instance, a 2½'' diameter pipe provides sufficient flow to a low head 12 kw installation. If there is high water volume and low head, a reaction type turbine is suitable.

Small Scale Hydro Systems: Water Turbines and Water Wheels

There are two basic classifications of hydro power machines — water turbines and water wheels. Water turbines spin at high speed and are used for electrical generation. Three small-scale turbines are considered here: impulse, reaction wheel, and cross flow. Water wheels are used for high torque mechanical purposes such as cutting or milling. Three kinds of water wheels are presented: overshot, breast and undershot.

Water Turbines

Impulse

The impulse or pelton wheel works by the force of a jet of water acting on cups mounted on the perimeter of a small wheel. No damming is required and the high-speed shaft can be directly coupled to a generator. The impulse wheel has a longer operational life (40 years) than most other designs. The disadvantage of this design is that sand and silt in the water erodes the cups (see Figure 5-3)

The power output ranges from 1 to 400 kw for the small units (to determine output from head and flow see Appendix H). Price ranges from $1000/kw for small units (1 to 35 kw) to about $750/kw for larger turbines. One model of an impulse turbine with a 2 kw generator attached is about five inches wide, a foot high, a foot and a half long and weighs 35 pounds. The turbine is fastened directly to the generator. The generator then produces a direct current which is wired to a band of deep cycle, lead acid storage batteries. When electricity is needed, current is pulled from the batteries and run through an inverter which converts 36 volt D.C. to 120 volt A.C. Installation of the complete system takes about one week.

Figure 5-3. Impulse Turbine

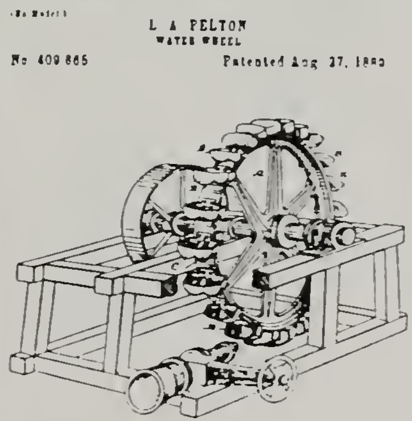
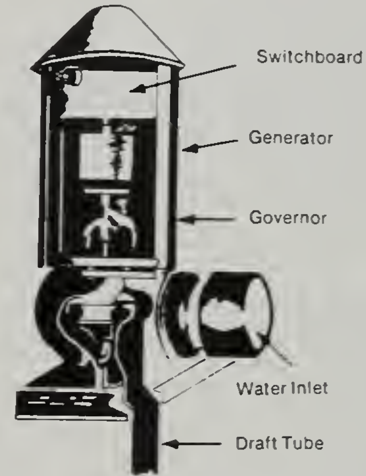


Figure 5-4. Reaction Wheel Turbine



Reaction Wheel

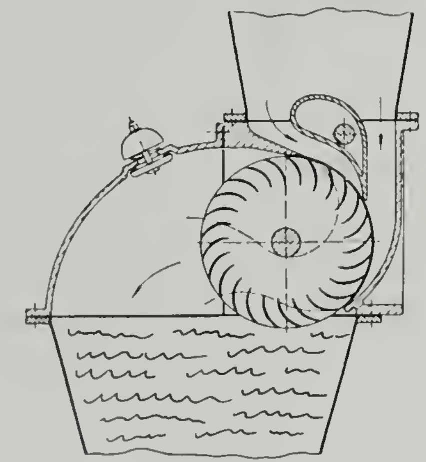
In a reaction wheel turbine, a propeller is turned by the fall of water through a duct or pipe in which the wheel is confined. This is the most compact type of water turbine for power output. Large reaction wheels can be coupled directly to a generator, but small units must be geared to match a high-speed generator. Sizes range from .5 to 10 kw using a head from 8 to 25 feet. The 10 kw unit costs $11,000. Life expectancy ranges from 10 to 15 years. Installation takes from 2 to 4 weeks. The disadvantages of the reaction wheel are rapid corrosion with silted water and high leakage and friction losses, especially in small units. (See Figure 5-4.)

Cross Flow

In the cross flow turbine (also called Ossberger) curved blades are designed to be hit twice by the falling water; three-quarters of the power is taken off the first pass and one-quarter off the second pass (see Figure 5-5). These units range in size from 8.5 kw to 220 kw. The design is essentially the same for a wide range of flows and heads (15 to 100 feet).

One advantage of a cross flow turbine is that it operates at optimum efficiency from 16 percent to 100 percent of flow. However, the complex blade arrangement can get clogged easily with grass, leaves and ice. Costs range from $1650/kw for small units to $2000/kw for larger ones (above 40 kw).

Figure 5-5. Cross Flow Turbine



Water Wheels

Overshot Wheel

With an overshot water wheel, water flows through a sluice gate to the top of a wheel of buckets causing the wheel to turn by the weight of the water and, to a slight extent, by the impulse of the water hitting the bucket. Because of the ease of construction, installation and operation, this water wheel has been favored for many years (see Figure 5-6). It is unaffected by sand, silt or minerals. The 1 to 20 kw output can be produced by a wheel with a diameter of .75 X head (heads range from 10 to 30 feet). The costs of these water wheels are difficult to determine, but could be as high as $1,000/kw.

Figure 5-6. Overshot Water Wheel

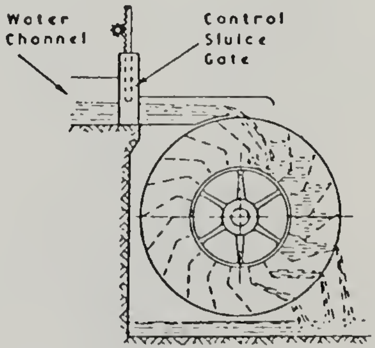
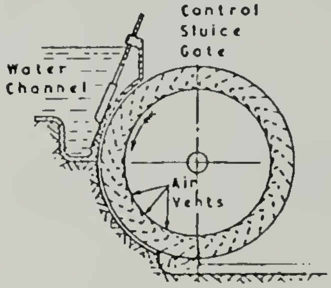


Figure 5-7. Breast Wheel



Breast Wheel

Water flows into buckets that trap the water by the concrete breast that is formed to fit close to the wheel. Air vents must be kept clear in the buckets to allow the water to enter. This is less efficient than the overshot and more expensive because of the careful breast construction (see Figure 5-7).

"I get a great deal of satisfaction out of using clean, renewable sources of energy to improve the quality of an individual's life."

William Delp
Noxon, Montana

Undershot Wheel

The undershot wheel is the simplest of all water wheels (see Figure 5-8). Although this type of water wheel has low efficiency, cost of construction and installation is low.

The use of water wheels in Montana will probably be restricted for several reasons:

- They are not factory produced; therefore, to reduce cost they must be fabricated by do-it-yourself operations. The life expectancy, operation, and maintenance are dependent on the quality of construction and installation.
- Due to the nature of Montana's weather, these wheels usually will produce only seasonal power and are therefore useful for seasonal mechanical uses (e.g., for agriculture).

Tables 5-1 and 5-2 summarize data on water wheels and water turbines.

"Turn off your lights; in the silence of your darkened home you can hear a thousand rivers whispering their thanks."

Clear Creek

Figure 5-8. Undershot Wheel

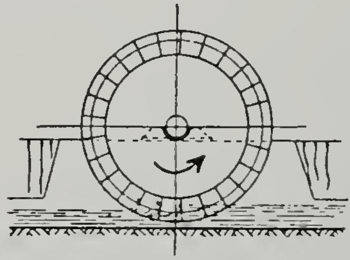


Table 5.1 Water Turbines

	Reaction (Hoppes)	Cross Flow (Banki Mitchell)	Impulse (Pelton)
Application	Electric Generation	Electric	Electric
Size Range	0.5 - 10 kw	8.5 - 220 kw	1 - 400 kw
Size Evaluation	10 kw	50 kw	100 kw
Head Range	8 - 25 feet	15 - 150 feet	50 - 4,000 feet
Head Evaluation	25 feet	100 feet	400 feet
Flow Range	70 - 500 cfm	400 - 1000 cfm	35- 400 cfm
Flow Evaluation	500 cfm	700 cfm	215 cfm
Efficiency of prime	80%	60 - 85%	80 - 94%
Overall	57%	50%	82%
Capital Cost $/kw	$1100	$1300	$750
Auxiliary Cost $/kw	$175	$700	$150
Yield (kwh/hr)	8.76×10^4	4.38×10^5	8.76×10^5
Total Capital Cost	$43/mm BTU/yr	$67/mm BTU/yr	$30/mm BTU/yr
Environmental notes	Ponding needed for low flow streams	Ponding needed for low flow streams	No ponding needed; long pipe needed to carry water down

SOURCE **Montana Conservation Plan**, Ecotope Group, Seattle, Washington, 1977

Table 5.2 Water Wheels

	Overshot	Breast	Undershot
Application	Mechanical	Mechanical	Mechanical
Size Range	1-20 kw	1-20 kw	1-10 kw
Size Evaluation	2 kw	2 kw	2 kw
Head Range	10-30'	6-15'	1-15'
Flow Range	3 cfm	3 cfm	3 cfm
Efficiency	60-85%	40-70%	35-45%
Capital Cost $/kw	$1000	$1000	$800
Auxiliary Cost $/kw	$300	$500	$200
Yield kwh/yr	17,520	17,520	17,520
Capital Cost	$43/mm BTU/yr	$50/mm BTU/yr	$33/mm BTU/yr
Environmental notes	Ponding needed	Ponding needed	very low impact; no ponding needed

SOURCE: **Montana Conservation Plan**, Ecotope Group, Seattle, Washington, 1977

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CHAPTER VI

BIOMASS ENERGY SYSTEMS

Introduction

''Wastes'' — animal manures, food scraps, harvest waste, human sewage, wood and wood wastes — are a relatively untapped resource. Collectible crop residues and feedlot wastes in the United States contain 4.6 quadrillion Btu (quads) — more energy than all the nation's farmers use. Generating methane from such residues is often economical. In May 1976, Calorific Recovery Anaerobic Process Inc., ot Oklahoma City, received Federal Power Commission authorization to provide the Natural Gas Pipeline Company annually with 820 million cubic feet of methane gas derived from feedlot wastes.

In China and India, ambitious programs to produce gaseous fuel from human and animal wastes are underway. Unfortunately, toxic industrial effluents are now mixed with human waste in many of the industrialized world's sewage systems, and these pollutants make clean energy-recovery more difficult. If these pollutants were kept separate, a large new energy source would be more readily available in this country.

Residues from the lumber and paper industries also contain usable energy. If the U.S. paper industry were to adopt the most energy-efficient technologies now available and were to use its wood wastes as fuel, fossil fuel consumption of the paper industry could be considerably reduced.

Unrecycled paper, rotten vegetables, cotton rags, and other organic garbage contain energy that can be recaptured economically. Baltimore, Maryland, expects to heat much of its downtown business district soon with fuel obtained by distilling 1,000 tons of garbage a day with biomass energy systems.

As the above examples suggest, biomass energy systems afford many possibilities for the conversion of plant and animal wastes to energy. In this chapter, the following topics are discussed: the conversion of wastes into bio-gas through anaerobic digestion; the potential of wood wastes and the effective use of wood burning stoves; and the conversion of wastes into alcohol fuels.

> *"We do know that conventional agriculture - at least as carried on in the U.S. - is no longer an energy producing segment of our economy. Tractor fuel alone, without considering the energy needed to transport synthetic fertilizers and pesticides, is about equal to the total energy yield of agriculture. That information comes from the excellent article "Farming with Petroleum", by Michael J. Perdman in the October 1972 issue of ENVIRONMENT."*
>
> Robert Rodale

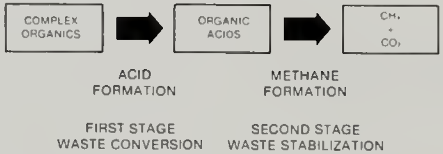
Bio-gas from Anaerobic Digestion

Anaerobic digestion is a process by which bio-gas is produced through the decaying of organic material in the absence of oxygen. Bio-gas contains methane, a combustible gas with a heat value of about 995 Btu/cubic foot (natural gas contains 1030 BTU/cubic foot). Methane is the main component of natural gas and is the burnable component of bio-gas (which also contains carbon dioxide, nitrogen, and traces of other gases). Scrubbing bio-gas by running it through materials which extract the non-combustible gas greatly improves its heat value. In addition to the generation of gas, anaerobic digestion of organic wastes produces an odorless, nitrogen fertilizer and soil conditioner.

In Montana, bio-gas production is suitable to large scale production: city sewage plants, feedlots and food processing plants. Production of methane from a single household is rarely worth the cost and effort from the amount of energy produced. This is particularly true in Montana because the productivity of methane plants in colder climates is greatly reduced due to the energy required to keep the plant sufficiently warm to operate. However, a sufficient amount of methane can usually be produced with a neighborhood or larger operation to make biogas production economically feasible.

In anaerobic digestion, organic waste is mixed with large populations of microorganisms in the absence of oxygen. Under these conditions bacteria grow which are capable of converting the organic material to carbon dioxide (CO_2) and methane gas (CH_4). Anaerobic treatment of complex organic materials is usually a two-stage process, as illustrated in Figure 6-1. In the first stage, such complex organic materials as fats, proteins and carbohydrates are biologically converted to simpler organic materials — for the most part, organic fatty acids. Acid forming bacteria bring about these initial transformations to obtain energy for their own growth and reproduction.

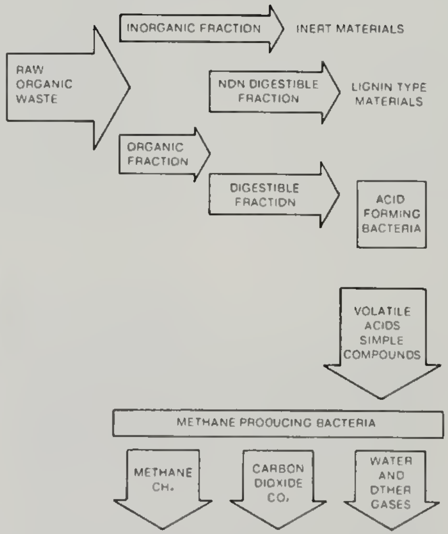
Figure 6-1 Two Stages of Anaerobic Digestion



SOURCE: **Other Homes and Garbage: Designs for Self-Sufficient Living**, Leckie, et al., Sierra Club Books, San Francisco, 1975.

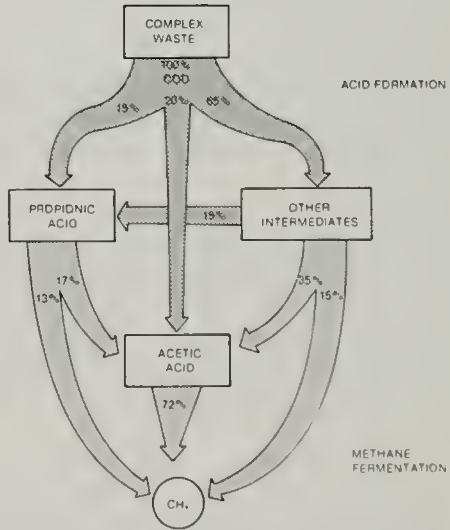
In the second stage of anaerobic digestion, the organic acids are converted by a special group of bacteria called the "methane formers" into gaseous carbon dioxide and methane. The methane-forming bacteria are strictly anaerobic and even small amounts of oxygen are harmful to them. There are several different types of these bacteria and each type is characterized by its ability to convert a relatively limited number of organic compounds into methane. The most important variety digests acetic acid and grows quite slowly and therefore must be retained in the digester for four days or longer. Figures 6-2 and 6-3 illustrate the process by which mixed complex organic materials are converted to methane gas.

Figure 6-2. The Biological Breakdown of Organic Material in a Methane Digester



SOURCE **Other Homes and Garbage: Designs for Self-Sufficient Living**, Leckie, et al., Sierra Club Books, San Francisco, 1975

Figure 6-3. Pathways of Methane Formation From Complex Organic Wastes



SOURCE **Other Homes and Garbage: Designs for Self-Sufficient Living**, Leckie, et al., Sierra Club Books, San Francisco, 1975

Digester Design

The conventional anaerobic treatment setup consists of a digestion tank containing waste and the bacteria used in the anaerobic digestion or fermentation process. Raw waste, introduced either periodically or continuously, is mixed with the digester contents. Mixing the organic materials as they undergo digestion is essential to the process. Although mechanical mixing is generally most common, some digesters mix the effluent by running gas back to the bottom of the digester and recirculating it through the mixture. The digester must be heated and insulated to maintain the anaerobic activity during the winter months.

The treated waste and microorganisms are usually removed together as treated sludge. Sometimes this mixture is introduced into a second tank where the suspended material is allowed to settle and concentrate before the sludge is removed (see Figure 6-4).

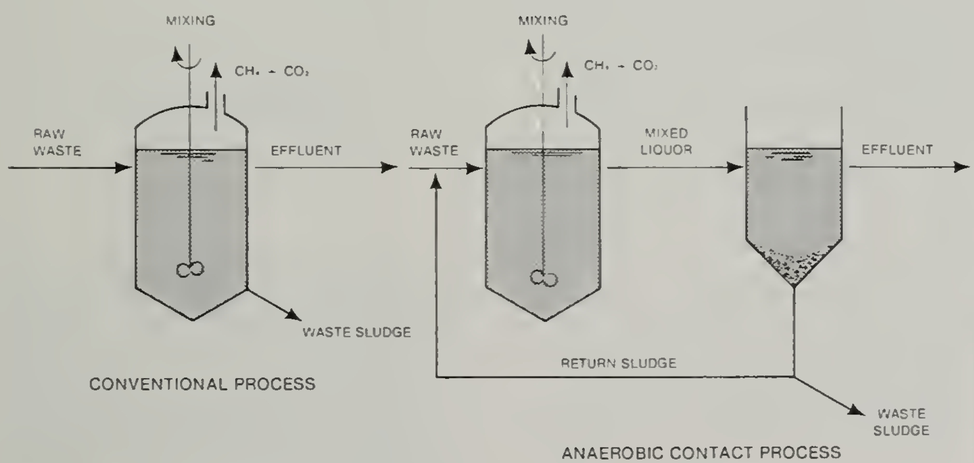
The gas itself is usually stored in a large tank with a top that fits inside it (made airtight by means of a water jacket) which can rise and fall with the amount of pressure exerted by the gas flowing in or taken out. It is not practical to compress or liquify bio-gas because of the amount of energy that must be used

Cost as well as the projected scale of the operation must be considered when choosing the type of feeding operation. The type and quantity of organic wastes which can be used as feed for the digester must be known. Also, it is necessary to know the composition of the various waste materials to insure that the bacteria have a well-balanced diet (with special attention paid to nutrients such as nitrogen). With this knowledge, the mixture and size of the actual input into the digester (slurry feed) can be calculated. Then the required size of the digester tank for specified conditions of temperature and residence time (the average time that the waste is in the digester before leaving as sludge) can be estimated.

Once the composition of the organic wastes and the temperature and residence time of wastes in the digester tank are known, the amount of gas which will be produced can be estimated and a collection tank sized. The gas tank should be large enough for several days' use.

Currently, small scale fuel production from bio-digestion is not economical because of the limited amount of fuel produced from organic wastes. Because of the presence of lignin in the feed, three-fourths of the energy available from the wastes cannot be converted to bio-gas. John Robbins, a chemist at Montana State University, is conducting experiments to delignify the organic wastes to make more cellulose and carbohydrates available for energy conversion. He has succeeded in increasing the fuel output five times under laboratory conditions.

Figure 6-4. Two Basic Methane Digester Designs



SOURCE: **Other Homes and Garbage: Designs for Self-Sufficient Living**, Leckie et. al., Sierra Club Books, San Francisco, 1975

"For every BTU used by the farmer in American agriculture he gets 1/5 BTU in return (from crops). For every BTU exerted by the Chinese peasant farmer he gets 56 BTU in return."
Article in **Environment Magazine**.

Wood

Introduction

Wood is usually measured in cords, which is equivalent to a stack of wood 4 × 4 × 8 feet = 128 cubic feet. About 70 percent of this volume is solid wood; the rest is air space. One pound of oven-dried (zero percent moisture content) wood has a heating value equivalent to 8,600 BTU; air dry wood (20 percent moisture content) yields about 5,700 BTU per pound; and green wood yields 10 to 44 percent less BTU than air dried wood. One pound of air dried conifer yields an average of 5,780 BTU. It would take 1.45 pounds of wood to equal the BTU content of one pound of coal, 20.7 pounds of wood to equal one gallon of oil, and 13.9 pounds to equal 100 cubic feet of natural gas.

Wood Burning

The key to efficiently heating with wood is a good woodburning device. The main factors governing wood stove and furnace efficiency are the control of air entering the wood box and the subsequent combustion of the wood gases. About 40 percent of the heat value from wood is derived from the combustion of gases after they are driven from the burning wood. In any wood burning device, combustion transforms wood into heat, chemicals, and gases through chemical combination of hydrogen and carbon in the fuel with oxygen in the air. Complete combustion produces water vapor and carbon dioxide along with heat and noncombustible ashes. When incomplete combustion occurs, carbon monoxide, hydrocarbons, and other gases are formed.

In the first phase of combustion, wood is heated to evaporate and drive off the moisture. The heat required to eliminate the moisture does not warm the stove or its surroundings.

The second phase of combustion begins at approximately 500° F when the wood starts to break down chemically and volatile matter is vaporized. When heated to approximately 1,100° F and mixed with the proper amount of air, these gases burst into flames and burn. If the temperature of the volatile gases is not maintained at approximately 1,100° F or if there is insufficient air, complete combustion does not take place. A hot fire is important for maximum efficiency in combustion.

In the third stage of combustion, the charcoal that remains after the release of volatile gases burns. The charcoal burns at temperatures exceeding 1,100 degrees F. Finally, a small amount of ash remains after the charcoal is burned.

The required control of combustion can only be obtained in airtight woodburners. In a well designed airtight woodburner, 50 to 60 percent efficiency is achieved in converting the energy content of wood to useful heat. In woodburner designs that are not airtight, the rate of combustion cannot be effectively controlled and a fire burns vigorously, releasing a lot of heat into the living space. The room gets too hot for a short period of two to three hours and then the fire subsides. In addition, the gases leave the flue at too high a temperature, dumping excessive amounts of heat out the chimney.

The extreme case of a non-airtight woodburner is the fireplace. Efficiencies of fireplaces range from 15 percent to −5 percent. The negative efficiency indicates that the fireplace can actually result in a net heat loss from the building. Devices that can be retrofitted to fireplaces, such as pipes used to convect (either by free or forced convection) heat from the fireplace to the living space do not increase the net output of the fireplace enough to justify their use. The poor performance of a fireplace is a result of the high rate of combustion and high stack temperatures that are created and the excess air that is drawn from the residence by the draft created through the chimney. An airtight woodburner can be retrofitted into a fireplace to improve its efficiency.

In airtight stoves, the rate of combustion is kept low. Wood burns at a constant rate for an extended period of time and, if the stove is properly sized, emits enough heat to keep the room at a comfortable temperature. The greater the combustion of the volatile gases and liquids prior to leaving the chimney or to being deposited as creosote, the greater is the woodburner's efficiency. Ideally, only enough air is supplied to provide the oxygen necessary to combust the volatile gases and charcoal. Excess air, instead of contributing to combustion, is itself heated and this heat is wasted when the air flows out of the stack, thus reducing the efficiency of the system. Some excess air, however, is required to promote turbulence which assists in mixing the hot volatile products with the air so that a more complete combustion can occur.

In airtight stoves and furnaces, the rate of combustion is controlled by limiting the supply of primary air so that insufficient oxygen is available to completely combust the gases. After volatile liquids and gases have been driven out of the wood, secondary air is supplied. Since burning of the volatile products requires a temperature of at least 1100° F the secondary air must be preheated to sustain combustion.

To preheat the secondary combustion air, either the secondary air flows over the hot coals, before contact with the volatile gases and liquids, or the air flows through chambers separated by a baffle (see Figure 6-5) that is being heated by the burning wood.

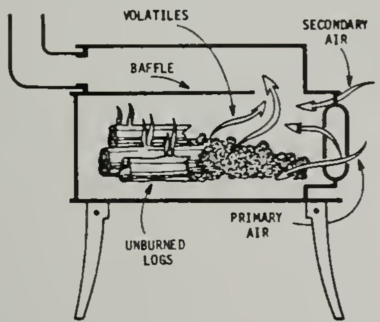
"Since 1959, farm use of electricity has increased 135% and the cost of power has tripled. In 1959 the range was from 265 kwh per month (in Louisiana) to 2,500 (in California). The national average was 558 kwh per month. This year farm use ranges from 780 (in West Virginia) to 4,700 (in California). National average is 1,311 kwh per farm per month. Eighteen years ago, cost averaged $12.56 per farm nationally. This year the monthly average farm bill is $48.10"

Montana Rural Electric News

Two means are generally used to control the primary air. One method uses a thermally controlled damper while another scheme allows for a manual setting of the amount of primary air. This second method of damping has been shown to work quite well with stoves that have a combustion chamber designed as shown in Figure 6-5.

Either scheme results in an efficient combustion of wood fuel. It is recommended that wood burning devices which are to be used as a source of heat for the residence be of an airtight design as discussed above.

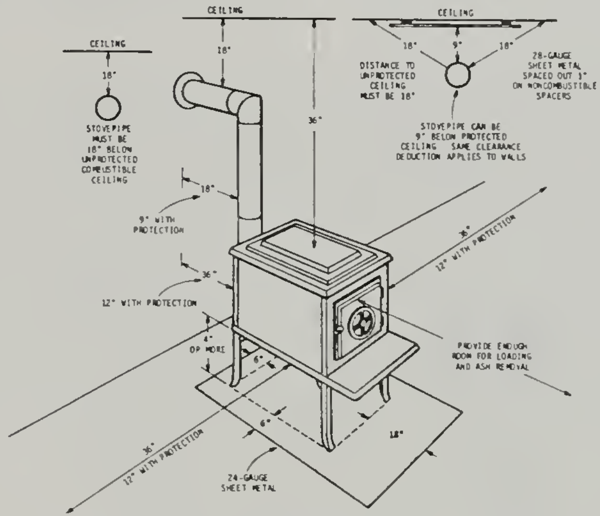
Figure 6-5. Typical Scandanavian Woodburning Stove



Most Scandinavian stoves use baffles to encourage a slow, even burn from the front of the logs to the rear. This cigar-like burning pattern prevents the whole fuel load from burning at once and eliminates the need for a thermostat.

SOURCE: **Heating with Wood** Publication #016, National Center for Appropriate Technology

Figure 6-6. Minimum Allowable Clearances for Radiant-Type Stoves



This shows minimum allowable clearances between radiant-type stoves and combustible surfaces. Combustible surfaces include plaster or wallboard construction even though you might not think of these materials as combustible. Clearances shown include both protected and unprotected surfaces. Approved protection consists of 28-gauge sheet metal spaced one inch from the wall on noncombustible spacers. The 24-gauge sheet metal under the stove may be covered with masonry such as patio blocks or flagstones set in mortar if desired. This provides a more finished look. Remember that these clearances are minimums and don't forget that furnishings such as furniture and curtains can be extremely combustible and can benefit from even greater clearances.

SOURCE: **Heating with Wood**, Publication #016, National Center for Appropriate Technology

Location

When installing a wood stove (or fireplace), it is wise to consult the local building inspector. If no building inspector is available, obtain a copy of the National Fire Protection Association's recommendations for the installation of wood heaters. Shortcuts should be avoided as responsibility for a safe installation rests solely with the owner. The following items are important considerations:

- Woodburning stoves should be installed certain minimum distances from any combustible surfaces (see Figures 6-6 and 6-7).

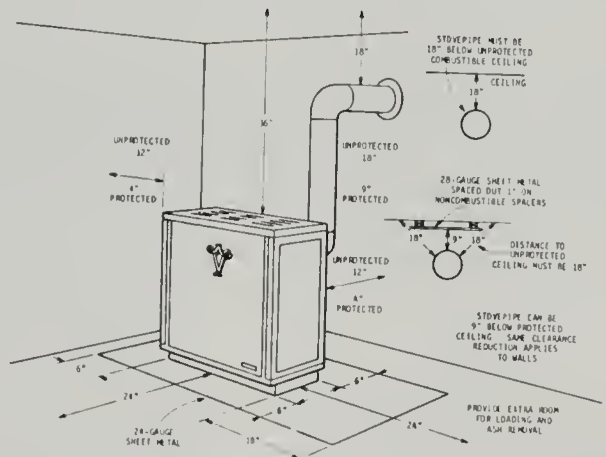
- Where will the location of the stove do the best job of heating? A good rule of thumb indicates that for the most even distribution of heat, a central, low location (basement) is preferred. Keeping the stove on the first floor or in the basement (better) makes for longer chimneys, better draft and better stove performance.

• How will the stove be vented? All wood stoves require a chimney or vent to get rid of combustion products. If the house already has an existing chimney, placing the wood stove close to that chimney makes sense. If the house has no chimney, the use of a prefabricated metal type may be the least expensive. Before installing a prefabricated metal chimney, consider the location of house framing members, walls, furniture located on floors above the stove, trees, and overhead power lines. If possible, outside air should be used for combustion. This requires proper ducting and attachment to the wood burner.

• A large percentage of residential fires associated with the use of wood are directly attributable to unsafe chimney installation. Recommended techniques for chimney installations are illustrated in Figure 6-8.

Of all types of chimneys, masonry chimneys with tile liners are preferred because of their durability and the protection they offer against chimney fires. A disadvantage is that heat is lost from the stack which may result in more creosote and soot deposits and slightly less draft. Masonry chimneys located against outside walls are especially subject to this problem. Locating a masonry chimney inside a house can take advantage of the heat loss of a chimney to help heat a house. This improves the heating efficiency of both the wood stove/fireplace and also of the central heating furnace (15 percent improvement versus 5 percent improvement for a metal chimney). A major advantage of masonry chimneys is their heat storage capacity. A masonry chimney located inside the house will continue to release its stored heat long after the fire has gone out.

Figure 6-7. Minimum Allowable Clearnances for Circulating-Type Stoves



This shows minimum allowable clearances between circulating-type stoves and combustible surfaces. As noted on the facing page, combustible surfaces include plaster or wallboard construction. Clearances are shown for both protected and unprotected surfaces. Approved protection consists of 28-guage sheet metal spaced one inch from the wall on noncombustible spacers. The 24-guage sheet metal under the stove may be covered with masonry such as patio blocks or flagstones set in mortar. Note that many circulating stoves are loaded through the side. Remember to provide enough room for loading and ash removal, and be sure to extend protective floor covering 18 inches on the loading side of the stove.

SOURCE **Heating with Wood** Publication #016, National Center for Appropriate Technology

Safety

Using wood for residential heating presents some serious safety problems. Among the problems are fire hazards caused by:

- radiation from the stove, stove pipe or chimney;
- sparks and glowing coals getting out of the stove;
- flames leaking out of faulty chimneys;
- conduction of heat from chimneys into combustible material;
- burning or glowing material coming out of the top of the chimney; and
- chimney fires.

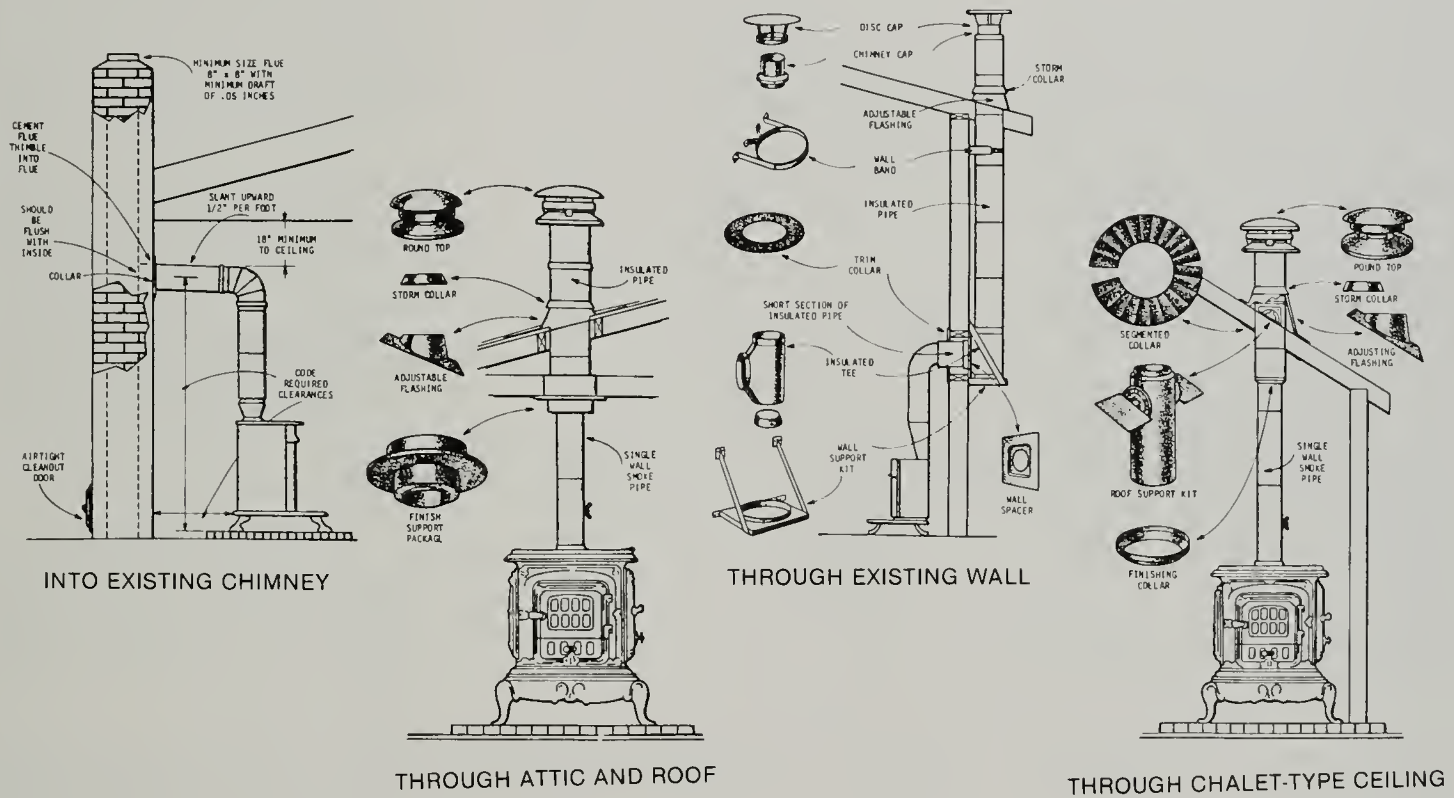
A good summary of safety tips is presented in **Heating with Wood** and reprinted here:

• *Start with good equipment, then inspect it yearly. Check stoves for cracks, weak legs, faulty hinges.*

• *Observe NFPA regulations. Allow for proper clearances between stove, stove-pipe and combustible surfaces. Remember that clearances shown in the installation sketches apply to wooden walls. Draperies and furniture are more easily ignited and require even greater clearances.*

• *Always vent your stove to a proper chimney. This should be a masonry or brick chimney, lined with tile or mortar, or a prefabricated Class "A" approved flue. The chimney should be straight from top to bottom, and smooth inside — without ledges to collect ash and creosote. It should extend three feet above the point where it exits the roof and two feet above any point on the roof within ten feet.*

Figure 6-8. Recommended Techniques for Chimney Installations



Here are hardware and techniques used to install stoves in a variety of situations. Shown left to right are venting into an existing chimney; through a typical attic and roof, through an existing wall and through a chalet-type ceiling.

SOURCE **Heating with Wood** Publication #016, National Center for Appropriate Technology

• Inspect your chimney before each heating season. Look for loose mortar, cracks, missing bricks and soot and creosote. Repair cracks with concrete and clean if necessary with a burlap bag stuffed with straw or paper and weighted with stones. The bag should fit the flue fairly snugly. Tie a rope to the bag, then lower it down the chimney and raise it back up several times. Cover the fireplace opening, or close the stove draft intake, to keep dirt out of the house.

• Inspect the stovepipe for corrosion. Clean before every season, and be sure all joints are fastened with three sheet metal screws.

• Check to be sure the damper is operating properly and that it can't accidentally close.

• Never pass a single-wall stovepipe through a wall or floor without the proper protection. Ventilated thimbles are good; multi-walled insulated stovepipe is even better. Stovepipe must rise at least ¼" per foot of length. Avoid more than two sweeping 90-degree turns.

• Avoid creosote production. Burn dry woods and favor hardwoods over soft woods. Some stove makers recommend a chimney fire once a week to avoid buildups that could cause a larger chimney fire. To do this, burn a few sheets of crumpled newspaper with damper and draft controls wide open. Commercial salts, made for cleaning chimneys, can be thrown on the fire once a week to achieve the same results without requiring a chimney fire.

• Do not overfire or underfire your stove. A roaring blaze creates too much heat and can ignite nearby walls or furniture. A smoldering fire creates creosote.

• Do not burn trash or manmade logs.

• Provide fresh air for the fire and the occupants for the house. Unless the home is particularly tight, however, there will be enough air through the cracks in the structure of the house.

• Use kindling to start fires, not gasoline or other hydrocarbons.

• Connect only one stove per flue. If a stove is connected to a flue above a fireplace, close off the fireplace opening with a sheet of metal or asbestos boards. Make sure the sheet closes the opening snugly.

Another question to be addressed is consumer protection and product liability insurance. Recent indications show that very few of the wood stove manufacturers can obtain product liability insurance for their products. A careful examination should be made before a unit is purchased.

Economic Considerations

To determine the economic advantage gained by heating with wood, consider:

- the present and projected cost of available wood;
- the future availability of wood for heating;
- the heating value of wood purchased (Table 2);
- the cost of the woodburner (prices for many good airtight woodburners vary from about $150 to $700);
- the efficiency of the woodburner;
- the cost of the exhaust stack or chimney and its installation;
- the projected cost of gas, oil, or electricity;
- the amount of supplemental heat expected from the woodburner;
- the expected lifetime of the woodburner and exhaust stack;
- the cost of any associated maintenance (e.g., cleaning chimney).

Under the correct set of conditions, wood heat can reduce the cost of heating a residence. From the above points it is apparent that any economic advantage of heating with wood over conventional fuels will vary from case to case.

Before choosing to supplement or replace the heat load requirement with a woodburner, consideration should be given to the above listed points to insure that operation of a woodburner is both economically advantageous and appropriate to the individual's lifestyle.

Alcohol Fuels

Some experts in fuel technology claim that much of the fuel that is needed now can be distilled from agricultural surpluses, timber waste, municipal garbage and wastepaper. These products can be converted into alcohol fuels, which can be blended into gasoline without changing engines, and with slight modifications automobile engines can be adjusted to run entirely on alcohol.

Neither the idea nor the technology is new European producers have sold alcohol blended with gasoline for decades. In the 1930's Chrysler Motors modified some cars slightly to accomodate alcohol fuels and shipped them to oil-short New Zealand. Earlier, in 1907, the U.S. Department of Agriculture published a report entitled "Use of Alcohol and Gasoline in Farm Engines" and in 1938 it published a booklet on "Motor Fuel and Farm Products." Today, the demand for ethanol as an additive to gasoline is steadily increasing.

There are a number of factors which tend to make alcohol a desirable component for blending with automotive fuel to make gasohol; the increased octane number which results from alcohol addition and the reduced fuel consumption of gasohol fuel compared to straight gasoline. In addition, the superior volatility of gasohol fuel enables a vehicle to start more easily in cold weather.

Although alcohol fuels are derived from either ethanol (grain or ethyl alcohol), or methanol (wood alochol), this section covers only the production of ethanol because ethanol is the most commonly used bio-fuel. Ethanol can be derived from any product with a high starch or sugar content such as wheat, barley, potatoes, and sugar beets — all grown in Montana. These agricultural products contain a renewable source of energy that can be grown every year utilizing free energy from the sun.

Production of Ethanol from Grain

Ethanol is fermented biologically from carbohydrates: sugar, starch and cellulose. Table 6-1 shows the carbohydrates used in ethanol fermentation.

Fuel and industrial grade ethanol greater than 95 percent concentration by volume requires distillate separation of the alcohol from the mash. Ethanol has a boiling point of 171° F which allows it to be vaporized from the fermented liquors, leaving most of the water behind. Distillation will yield to 94 to 96 percent pure ethanol. Purification beyond this point is economically senseless for most fuel and/or industrial processes. Pure ethanol has a heat value of 12,800 BTU/lb and an octane number of 99.

Ethanol from sugar crops has demonstrated the highest process efficiency, since the enzymes for conversion are present in those crops and no special preparation is necessary. Ethanol from starchy crops requires that a mash be formed and steamed under pressure. Then, an enzyme derived from grains is needed to release the sugar from the starch by splitting out the water molecules which entrap the sugars.

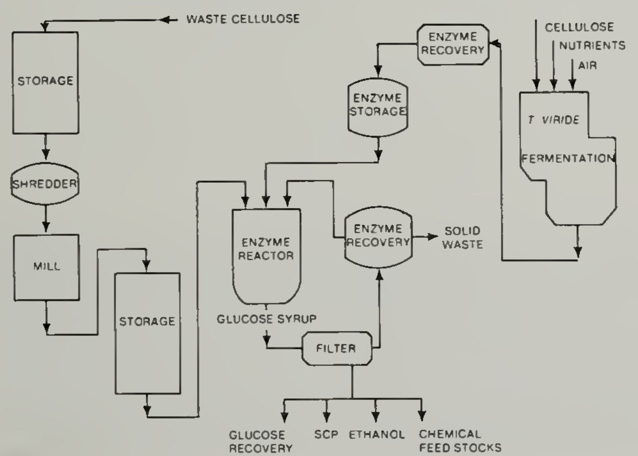
Table 6.1 Carbohydrates Used in Ethanol Fermentation

Carbohydrate	Example
Sugars	Table sugar (sucrose)
	Milk sugar (lactose)
	Fruit sugar (fructose)
	Dextrose (glucose)
	Malt sugar (maltose)
Starches	Rice
	Corn
	Potatoes
	Wheat
	Barley
Cellulose	Wood
	Paper
	Straw
	Stalks

The most promising breakthrough for conversion of cellulose into fermentable sugars appears to be a process developed at the U.S. Army Laboratories at Natick, Maine. This process is illustrated in Figure 6-9. A clothes-destroying fungus, *Trichoderna viride*, discovered by the Quartermaster Corps during WW II in the South Pacific, is central to the conversion ol cellulose. The Army lab at Natick irradiated *T. viride* to produce mutant strains which possess a heightened ability to cause rot in wood and cellulose material. *T. viride* works by producing cellulase, an enzyme which acts on cellulose to convert it to glucose syrup. This syrup can be used as a chemical feedstock when changed to pure glucose or converted by fermentation to ethanol.

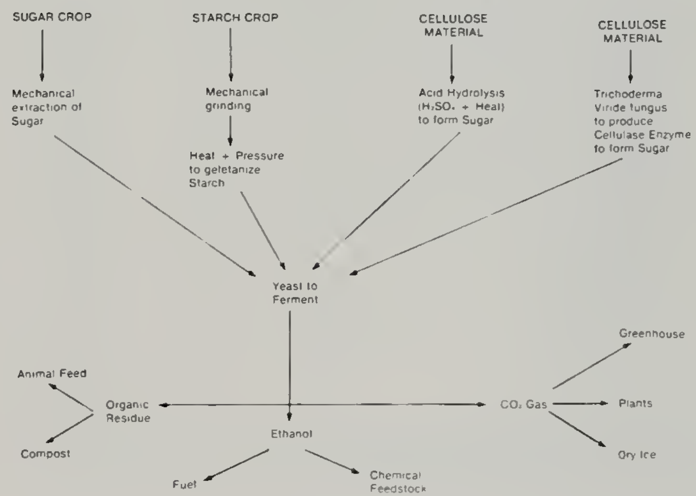
Many products may be produced from the fermentation process, as shown in Figure 6-10.

Figure 6-9. Enzymatic Conversion of Waste Cellulose



SOURCE Andren and Nystrom, 1976

Figure 6-10. Products from Fermentation Process



Commercial Application of Gasohol

Although ethanol for gasohol is not currently produced in Montana, gasohol is now sold in parts of eastern Montana and plans are underway for the construction of ethanol plants.

Several farmers near Lewistown have been using a gasohol blend (20 percent ethanol distilled out of state and 80 percent gasoline) for a few years and are satisfied with its performance. Their vehicles are better starting, have more power and run more smoothly. In August 1978, a service station in Wolf Point became the first to sell a gasohol blend (distilled in Illinois) in the state.

The interest in gasohol is considerable among ranchers and farmers in Montana, who believe that gasohol can reduce the consumption of petroleum products. Tables 6-2 and 6-3 present the petroleum consumption of Montana's agricultural sector.

A promising method for producing ethanol on the farm is hydrolysis. Plant material is placed in a tank with a specified amount of water and an enzyme. This mixture is continually agitated and held at a constant temperature (115°-125°F) and acidity for 24 hours. During that time the enzyme will break down the cellulose contained in the mixture and convert it to glucose. After 24 hours, the tank is drained and the remaining slurry pumped through a filter. Roughly 1400 lbs. of solid materials are collected in the filter after a one-ton batch has been hydrolized. These solids can be used as fertilizer, dried further and burned in a home-heating furnace, or sold for processing into a high-protein feed supplement. The glucose syrup coming through the filter can be fermented into fuel.

Farmers and ranchers probably could keep enough glucose fuel to meet their own fuel needs and sell the remainder. The fuel will burn in any oil-burning stove or diesel engine. It also can be used in a gas engine with minor modifications to the engine. The syrup can be fermented into ethanol and/or processed into virtually any other product now made from petroleum—ethylene, as gas, is one possibility; xylitol, a new sweetener that may replace saccharin, is another.

Table 6.2 Total Energy Requirements for Major Crops in Montana (1973)

Crop	Diesel Fuel	Gasoline	Total Energy
	(thousands of gallons)		(millions of BTU)
Alfalfa (I)	3,597	6,382	1,294,948
Alfalfa	1,012	837	245,468
Barley (I)	1,186	937	282,228
Barley	2,657	8,158	1,383,572
Dry Beans (I)	48	118	29,264
Corn, Silage (I)	1,197	489	228,216
Hay (I)	2,124	2,877	654,108
Hay	2,530	2,249	633,076
Oats (I)	151	355	65,160
Oats	492	1,471	251,284
Pasture (I)	276	556	457,584
Spring Wheat (I)	205	369	74,456
Spring Wheat	3,219	8,552	1,511,108
Sugar Beets (I)	925	1,006	254,244
Winter Wheat (I)	129	153	37,032
Winter Wheat	3,067	8,704	1,508,676
Subtotal	**22,815**	**43,213**	**8,552,512**
Summer Fallow	20,543	3,785	3,345,360
Total	**43,358**	**46,998**	**11,897,872**

The symbol I indicates irrigated production
SOURCE Energy Consumption by Forestry and Agriculture in Montana Terry Wheeling Montana Energy Advisory Council July 1976

Table 6.3 Estimate of Fuel Burned in Montana Livestock Production Under Average Conditions

Livestock		Fuel Used Per Unit		Total Fuel Used	
		Gasoline (Gallons)	Diesel (Gallons)	Gasoline (Gallons)	Diesel (Gallons)
Sheep - 1972	950,000	60 P U	45 P U	570,000	427,500
Hogs - 1971	245,000	40 P U	30 P U	98,000	73,500
Cattle - 1972	3,165,000	90 P U	65 P U	2,848,500	2,057,250
		[1]3,037,375 Average		3,516,500	2,558,250
		Gasoline	Diesel		
	Ratio	75 percent	25 percent	2,278,031	759,344

This figure reflects the total amount of each fuel used if it were used exclusively
This figure is the average and total gallons of both fuels used for livestock production
SOURCE Energy Consumption by Forestry and Agriculture in Montana Terry Wheeling Montana Energy Advisory Council July 1976

Not long ago, the editors of the Farmer-Stockman printed a picture of a deserted farmhouse in a desolate, sandswept field, then offered a prize for the best 100 word essay on the disastrous effects of land erosion. A bright Indian lad from Oklahoma bagged the trophy with this graphic description:

"Picture show white man crazy. Cut down trees. Make to big teepee. Plow hill. Water wash. Wind blow soil. Grass gone. Door gone. Squaw gone. Whole place gone to hell. No pig. No corn. No pony.

Indian no plow land. Keep grass. Buffalo eat grass. Indian eat buffalo. Hide make plenty big teepee. Make moccasin. All time Indian eat. No work. No hitch-hike. No ask relief. No build dam. No give dam. White man heap crazy."

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CHAPTER VII

GEOTHERMAL ENERGY SYSTEMS

Introduction

Geothermal energy, the natural heat of the earth, is a vast potential source of useful energy which can become available for a variety of applications as cost-effective technologies are developed. The decay of radioactive elements deep in the earth and shallow magmatic intrusions (hot rocks) are the major sources of the enormous quantities of heat trapped underground. Temperatures generally increase the deeper one penetrates toward the center of the earth. The normal geothermal gradient (the average temperature rise as depth increases) is on the order of 1-2° F with each 100 feet of depth—about 75° to 80° per mile. Temperatures in the center of the planet may be as high as 6,000 to 8,000° F. The theoretical energy potential of this heat is staggering.

The resource base of the hot dry rock in the United States to a depth of 10 kilometers (6.2 miles) is about 32 million quads (1 quadrillion = 10^{15} BTU). About 40 percent of this, 13 million quads, occurs at temperatures greater than 302° F. If only 2 percent of this 302° F resource base could be economically exploited, then at the present annual rate of energy consumption in the U.S., this resource could potentially supply the nation's nontransportation energy needs for more than 2200 years.

In the foreseeable future only those few reservoirs close to the surface are likely to be utilized. Surface manifestations of geothermal energy include hot springs, geysers, fumaroles and pools of boiling mud such as those found in Yellowstone Park.

Since geothermal energy, unlike solar energy, is not readily available to most Montanans, this chapter presents only a general overview of geothermal potential and application in the state.

"...I don't mean that we should revert to building sod houses, log cabins or Indian teepees. We should be rooted in the past, but not stuck in it. If our forebears found out the hard way how to cope with wind, sun, snow and dust, we can perhaps take over from them one or the other element, but it all has to be re-created in terms of the knowledge, needs, and technology of nineteen-seventies."

Wilbur Wood
Sun-Times

Geothermal Structures

Geothermal regions are usually (although not always) associated with known volcanic activity, young intrusive rocks, and/or earthquake zones where water works upward to the surface of the earth

There are four kinds of geothermal fields

Hot water fields contain a water reservoir at temperatures ranging from 140 to 212° F They can be useful for space heating as well as for other purposes such as industrial process heat

Wet steam fields contain a pressurized water reservoir at temperatures exceeding 212° F They may be useful for power generation as well as for other purposes such as industrial process heat.

Dry steam fields yield dry (superheated) steam at the wellhead with the temperature about 400° F They are suitable for power generation

Hot, dry rocks are 600° F or hotter rocks below the earth's surface which can be fractured Water is forced down the fracture turns to steam and is conducted to the surface in a second well to run an electric turbine This technology is experimental and has not been developed commercially

Geothermal Applications

Major interest in geothermal energy worldwide has focused on power generation A major reason for this is that geothermal resources must be exploited where they occur which is often remote from urban areas Electrical transmission lines make transport of power from geothermal electrical production facilities possible Lardarello Italy Wairakei New Zealand and the Geysers in California are examples of productive geothermal power stations

There are two basic types of geothermal energy moderate to high temperature sources for electrical generation and moderate to low temperature sources used primarily for space heating High-temperature resources with desirable chemical characteristics for use in stream turbines are rare. Multiple-use development of geothermal resources in the intermediate range (from 212° F to 302° F) is probably limited to electrical energy production and possibly mineral recovery

The most important use of moderate to low temperature geothermal heat (less than 248° F) is space heating Currently geothermal potential for space heating is relatively untapped In Iceland, 40 percent of the population lives in houses heated by geothermal water Japan, New Zealand, the Soviet Union and the United States are beginning to use geothermal for heating homes, hotels, apartment complexes, and public buildings

For instance geothermal waters at Klamath Falls, Oregon have provided heat for about 500 buildings, a swimming pool, a milk pasteurization plant and snow melting facilities for roads The total heat load approximates 5 6 MW Nearly 400 wells of depths ranging from 83 to 1788 feet are used Estimated costs for a single well vary from $5,000 to $10,000 and the annual operating cost per well is less than $100

In Boise, Idaho, a small geothermal space heating system was established in the Warm Springs residential area in 1890 This project received little official attention, however, until 1975 when a joint federal-state effort to convert existing systems in several state-owned buildings to geothermal water began The total annual fossil fuel expenditure for the ten buildings under consideration for this conversion is $240,000 Full implementation of the proposed system will provide year-round heat to the ten state buildings plus thirty additional buildings, all at less than 70 percent of current fossil-fuel heating costs

The technology for using geothermal water for space heating is well developed If the water is of high quality (moderate temperature and a small quantity of dissolved solids), it can be piped directly to building heating systems. When the geothermal water has a high content of dissolved solids, heat exchangers must be used to minimize problems with precipitation of minerals and corrosion

If the geothermal water temperature is too low for direct applications, it can be used to preheat water or it can be the heat source for an electric heat pump

Geothermal Resources in Montana

Although Montana is known for its geothermal hot springs, actual exploration and use of this resource has been limited. The U.S. Geological Survey has classified four areas in Montana as known geothermal resource areas: West Yellowstone, Corwin Springs, Marysville and Boulder An additional 3,834,000 acres have been classified as prospective areas of geothermal resource value Figure 7-1 shows specific geothermal sites across the state

The hot springs of southwestern Montana are all of the warm water type without steam. Their discharges are quite low, less than 1000 gallons/min except for two large low-temperature springs, the waters of which are used for irrigation Some of the warm springs may result from the mixing of deep hot water and shallow cold water With the exception of one spring, which had been disturbed, none of the temperatures of the other springs varied by more than 5° F during a four-year period.

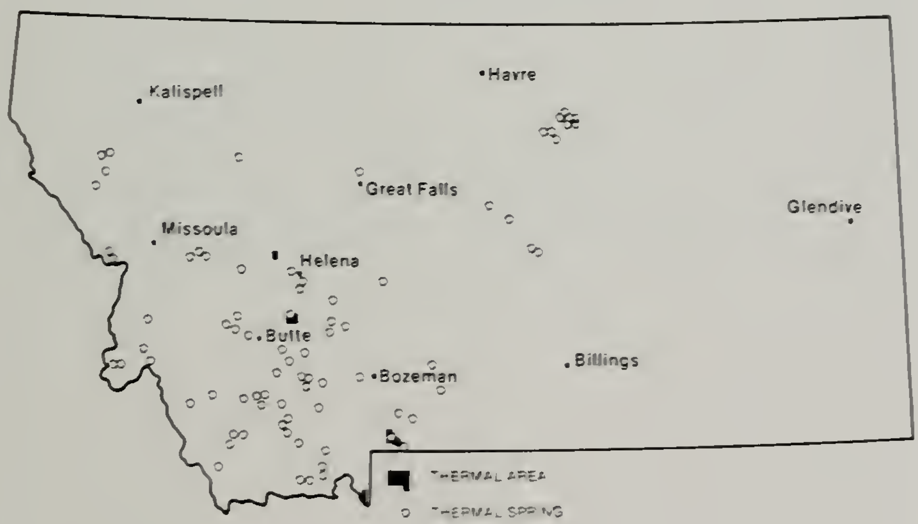
Not much is known about the Madison aquifer which is as much as 10,000 feet below much of the central and eastern part of the state, except that it is a large reservoir of hot water This reservoir can be tapped by drilling deep wells Future exploratory drilling in Montana will probably reveal numerous concealed (sub-surface) reservoirs

Utilization of Montana's Geothermal Resources

Although Montana does not have the known geothermal potential of California, Nevada or Idaho, it is probable that future exploration for reservoirs will unearth additional resources.

The maximum recorded underground water temperature in Montana is not hot enough for generating electricity, but is more than adequate for such applications as space heating and greenhousing. In areas of Montana such as the Little Rocky Mountains where warm water (84° F) is plentiful, the irrigation of crops to stretch Montana's short growing season can be extended by using warm water for the irrigation of crops. A truck gardener south of Dillon gets an extra two to four weeks at the beginning and end of each growing season by irrigating with warm water. And ranchers in the Centennial Valley use 82° F water to irrigate grassland. By combining longer irrigation seasons with geothermally heated greenhouses, crops could be grown year-round.

Figure 7-1. Geothermal Sites Pinpointed Across Montana



As fossil fuel prices continue to rise, geothermal space heating systems could become attractive to small communities. Excellent opportunity for geothermal space heating exists in the Boulder area, Helena, Ennis, Bozeman, and at White Sulphur Springs. The First National Bank in White Sulphur Springs has used a state grant to install a geothermal heating system. Other areas which are good candidates for geothermal space heating are the towns of West Yellowstone, Ennis and Broadwater. Warm Springs State Hospital, heated with conventional fuel, will be converted to geothermal for space heating.

In addition to agricultural application and space heating on an individual or district basis, Montana's geothermal resources could provide hot water for domestic, commercial, and industrial process through a simple heat exchange mechanism. Circulating hot water around digesters would facilitate methane production. Geothermal could also be applied to food processing and drying. Geothermal is particularly attractive for aquaculture where catfish and other species could be commercially grown and sold for human consumption. Street de-icing is another possible application. And although recreational use of hot water has been a successful historical use of Montana's hot water, these recreational facilities could be expanded and new ones constructed. The potential uses of Montana's geothermal resource are considerable.

> *"We have probed the earth, excavated it, burned it, ripped things from it, buried things in it, chopped down its forests, leveled its hills, muddied its waters, and dirtied its air. That does not fit my definition of a good tenant. If we were here on a month to month basis we would have been evicted long ago."*
>
> Rose Bird, Chief Justice
> California Supreme Court

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ALTERNATIVE RENEWABLE ENERGY GRANTS PROGRAM PROJECT SPOTLIGHTS

The Oien Home ______ Conrad, Montana
Active Solar Space and Water Heating Retrofit

William Kilby's Concentrating Tracking Collectors Great Falls, Montana
Residential Retrofit to Provide Space Heat and Domestic Hot Water

The Harriman Project ______ St. Ignatius, Montana
Heat Pump Utilizing 52° F Constant Artesian Well Water with Integrated Greenhouse Demonstration

The Fowlkes House ______ Bozeman, Montana
Passive Solar Heat Collection and Trombe Wall Storage with Integrated Backup Wood Heat and a Solar Hot Water Preheater

The Mattson House ______ Bozeman, Montana
Active Air Collection and Rock Storage Integrated With Passive Design Features

John Brown's Windborn Farm ______ Circle, Montana
Solar Greenhouse

Gary J. Franklin ______ Great Falls, Montana
Passive Solar Greenhouse Retrofit with Supplement Wood Heat

The Bass Creek Commune ______ Stevensville, Montana
Integrated Solar Wind and Wood System

The Oien Home
Conrad, Montana

Active Solar Space and Water Heating Retrofit

Design and Construction
Orville and David Oien

Microclimate

Through the period 1941 through 1970, Conrad has averaged 8142 heating degree days annually. Between 1931 and 1960, Conrad averaged temperatures of 43.1°F yearly, with a high monthly average of 67.0°F in June and a low monthly average of 19.6°F in January. At this writing, solar flux (intensity) measurements for Conrad are incomplete, but readings for Great Falls at a 60° angle suggest an average daily high 478 langleys in April and a low daily average of 170 langleys in January. Precipitation averages 12.2 inches a year.

System Design

After David Oien took an Aero-West sponsored solar design class in Missoula, he suggested to his father the possibilities of a solar retrofit on their Conrad farmhouse. They came up with an active system utilizing a large reflector area to provide their 1550 square foot home with supplemental space heat and domestic hot water without major structural changes.

The collector design was adapted to local weather conditions—strong winds, hail and extreme cold. They positioned the collector array within a shed upon the home's south-facing roof. Ninety-six square feet of 50/50 ethelyne glycol-water collectors (tube-on-plate absorbers by Olin Brass) were mounted on the roof at a 63° angle. They were protected by double-glazed patio door glass bought at salvage for less than $125. The shed was built behind the collectors by extending the north sloping roof to the top of the collectors. The inside of the shed was lined with reflector aluminum sheets and aluminum faced shutters lie on the roof in front of the collectors. The shutters can be raised and closed to protect the collectors and prevent heat loss. Altogether there are 450 feet of reflective surface. The ethylene-glycol/water solution passes from the collectors through coiled copper tubing to transfer heat into fourteen 120-gallon glass lined water storage tanks. When space heat is required for the home, water is circulated from the storage tanks to a water to air heat exchanger located in the cold air plenum of their existing forced air furnace. The stored heat is then circulated throughout the home through the use of its conventional heating system and ducting.

In order to avoid contamination of domestic hot water, a separate 40 gallon preheat tank has copper tubing circling it on the outside to exchange heat from the collector fluid to the domestic water system.

Operation

A Deko-Labs Model TC-3 differential thermostat switches the collector pump "on" when the collector temperature exceeds the stored water temperature by a predetermined temperature difference. The thermostat also switches the pump "off" if the collector cools or the storage temperature increases when there is only a 5°F temperature difference. By adjusting several valves, it is possible to increase the system's efficiency by reducing the storage volume to a volume more appropriate to the amount of heat delivered by the collectors.

Performance

Once installed, the collectors worked well though it was five weeks later before the reflector system was added. Efficiency of the system increased noticeably once the reflectors were mounted. The Oiens estimate the system saved them $230 on space and water heat during its first year of operation.

Several monitoring devices were installed, including temperature probes, elapsed time counters and strip chart recorders, to accurately determine the system's performance. The measured performance of the system between July 1977 and December 1978 was:

Domestic hot water system	4,290 BTU/kWh
Air heating system	5,470 BTU/kWh

These should be compared to the following conventional heating sources:

Electric hot water heating	2,000 BTU/kWh
Electric resistance heating	2,400 BTU/kWh

From July 1977 through June 1978, the solar space heating system operated at an efficiency of 46 percent and the solar domestic hot water system performed at a 28 percent efficiency. These amounts represent the total solar heat delivered to the home compared to the total solar energy available.

During the same period, total household heat demand for space and water heat was 63 million BTUs, of which solar heaters provided 26 percent, the heat pump 51 percent and electric heaters 23 percent.

Problems

Design problems: "These consisted of those never resolved questions like how much collector area would be best and how much and what kind of storage?" Construction problems: "Our project has too many angles, plants and plumbing connections. Some can be rectified, some must be endured." Orville Oien

Modifications

The heat exchange system was designed to transfer heat from the water storage tanks to the cold air plenum of their oil burning furnace. However, even though the shed housing the storage tanks was well insulated, an appreciable amount of stored heat was lost there, providing heat to the 800 sq. ft. shed, which could not be transferred to the house. A solution suggested by Oien would be to move the tanks to a different part of the house. Placing the tanks in a well insulated crawlspace and venting the warm air directly into the living space (utilizing the concept of convection) should greatly improve the system's efficiency. Since the tanks act as radiators, no plumbing into a circulation system would be required.

Tips

"In the short and long term, the best solar heating system is the least complex, the easiest to understand and the easiest to repair."

"I would suggest researching as many installations as possible, consider your particular circumstances (don't forget Montana's sub-zero winters and her sometimes destructive hail storms,) and always do things as simply and directly as possible." Orville Oien

Financing

The intial system cost was $7,987.21. A $7,276 state renewable energy resource grant was awarded the Oiens.

Equipment

Thermopane patio door glazing

Tube-on-plate Roll-Bond absorber by Olin Brass

Reflectors, delta-rib, aluminum roofing

14 120-gallon Sears glass lined water storage tanks wrapped in 6 inches of fiberglass insulation.

Monitoring

On a daily basis, the Oiens record the number of hours the system collectors are active (pump in operation) and the 9 a.m. and 12 noon outside temperatures. Collector and storage temperatures will be monitored once proper equipment arrives.

Budget

Salaries	$2,146.92
Building materials	4,587.63
Equipment	858.66
Supplies	159.63
Administration & other	104.37
	$7,857.21

William Kilby's Concentrating Tracking Collectors Great Falls, Montana

Residential Retrofit to Provide Space Heat and Domestic Hot Water

Design and Construction
William C. Kilby
Engineering - Drapes, Great Falls, Montana

Microclimate
William Kilby's house is located at 3313 5th Ave. North in Great Falls. Measured at a 60° incline, solar intensity peaks in April with a daily average of 478 langleys a day. January insolation averages 170 langleys. Between the years 1931-1960, temperatures averaged 44.7°F with a high average of 69.4°F in July and a low average of 22.1°F in January. During the years 1941-1970, Great Falls averaged 7652 heating degree days annually. Great Falls averages 14.1 inches of precipitation yearly. Average mean wind speed in Great Falls is 13.1 mph.

System Design
William Kilby wanted to add a solar heating system to his residence which could be integrated with his existing gas-fired boiler hot water heating system, designed to operate using water at 180°F. His solution was to mount an array of 32 Northrup tracking, concentrating collectors in two banks at a 45° angle on his roof.

When in operation, 40 gallons of a 50% water-50% ethylene-glycol solution (good to -34°F) is pumped through the collectors. A Bell and Gossett heat exchanger is used to transfer heat from the solution to water in four 250 gallon fiberglass storage tanks located in Kilby's garage. The water is circulated through standard finned-tube radiators to provide space heat to the house. In addition, the antifreeze solution circulates through an American Heliothermal 82-gallon tank with an outer shell heat exchanger to provide the Kilbys with domestic hot water. Their existing gas fired boiler is tied into the system to provide backup heat. The solar system was designed to supply 50 to 60 percent of the house's annual heating load.

Operation
The system may be operated manually or automatically. Each array of 16 collectors has its own tracking and drive system. A Rho Sigma differential thermostat is set to turn on the solar circuit pump when collector temperature rises to 17°F above the tank temperature. The thermostat will turn the pump off when collector temperature drops to 2°F above the storage tank temperature. A photoelectric electric sensor for each array stops each tracking collector array when the array reaches a maximum allowable temperature. One array is set to stop 20°F lower than the other to provide variable capacity in summertime. Each storage tank is in series and individually valved so system storage capacity can be varied and optimal temperatures can be obtained. Either one, two, three or all four of the tanks can be used for storage. Pneumatic valves are interlocked with the solar system pump so that when the pump is on the valves are open and when it's off the valves are closed in order to prevent gravity circulation in the solar circuit. A pneumatic reset control at the storage tanks will turn on the backup system when storage system temperatures are not high enough to provide sufficient heat.

Performance

The first full day of **manual** operation of the system was February 20, 1978. On March 11, 1978, the Kilbys raised the temperature of 500 gallons of storage system water from 92°F to 141°F in 7½ hours of operation with sky conditions of bright sun to hazy back to bright. Heat gain that day totalled 204,300 BTUs or an average of about 28,000 BTUs per hour. Kilby's preliminary observations suggest that the collectors are very efficient and will operate as expected, lowering his gas bill in the range of $300 to $350 a year. Kilby believes his domestic water preheater is not as efficient as expected because of insufficient heat exchanger surface and design. Kilby feels a shell and tube type heat exchanger would be more efficient than the shell-in-a-shell type, though other solar innovators have found the shell-in-a-shell type an adequate design.

Problems

"One must have, or develop, patience when dealing with the solar industry and mechanical equipment supply houses; they tend to distort the facts about prices and delivery dates. My collectors were promised to be shipped 'in two weeks after receipt of order.' They were ordered in the first part of June and received in mid-September, 3½ months later."

Modifications

None yet.

Tips

"Such systems should be carefully designed and planned by one with expertise in such design. There are many variables unknown to the layman which could thwart a system not studied and planned properly. The economics and life-cycle-cost should be given careful attention."

Financing

$14,100 state renewable energy grant, $1,000 out-of-pocket expenses, 524 hours in-kind labor.

Equipment

Collectors - 32 Northrup Inc. concentrating collectors, Model MF-NSC-P(BC-G)
Heat exchanger - Bell and Gossett No. WU66-42, 2" baffle spacing
Water preheater - American Heliothermal 82-gallon tank with outer shell heat exchanger
Solar circuit pump - Grundfos No. UPS 26-64F
Storage circuit pump - Bell & Gossett No. 1¼HP
Water preheater pump - Grundfos No. UPS 20-42F

Controls

Differential thermostat - Rho Sigma No. RS106
Photo-electric sensor - Johnson Controls
Pneumatic valves - Johnson Controls

Monitoring

Thermometers and pressure gauges are located throughout the various circuits.

Insulation

Ceiling, R38; Walls, R13.

Budget

A. Expenses		
Collectors (freight included)	$ 6,940	
Support frame and storage tanks (separate costs unavailable)	1,850	
Domestic Water Heater	620	
Expansion Tank	430	
Heat Exchanger	450	
Insulation	575	
Antifreeze (3 fills)	175	
Piping, Fittings, Solder, etc.	2,700	
Electrical	100	
Pumps	180	
Trenching, Concrete Work	1,000	
Electrical Controls	125	
Miscellaneous Items	367	
TOTAL		$15,512
B. Donated Materials (Estimated)		
Storage Tanks	750	
Control System (Johnson Controls)	$ 1,250	
Personal Supplies & Materials	200	
System Design (Drapes Engineering)	1,000	
TOTAL		$ 3,200
C. Summary		
State Grant (Contracted Amount)	$14,100	
Donated Materials	3,200	
Personal out-of-pocket expense	1,142	
TOTAL (NO LABOR)		$18,612

The Harriman Project
St. Ignatius, Montana

Heat Pump Utilizing 52°F Constant Artesian Well Water with Integrated Greenhouse Demonstration

System Design and Installation -
Margaret and David Harriman

Microclimate
The Harrimans' property is protected from winds by 50-foot clay bluffs to the north. The water table on their property in a swampy, marshy area at the foot of the Mission Mountains is at the one-foot level. In this damp atmosphere, they regularly suffer a very early frost and a short outdoor growing season. Temperatures in St. Ignatius (through the period 1931-1960) averaged 46.0°F annually, with an average monthly high of 67.6°F in July and an average low of 25.1°F in January. Through the period 1941 through 1970, St. Ignatius averaged 7197 heating degree days annually. Recent (but incomplete) solar intensity data taken at a 60° angle at nearby Polson suggests an average low of 165 langleys in January and an average high of 437 langleys in April.

System Design
In swampy bottomland at the base of the Mission Mountains, David and Margaret Harriman have long utilized artesian water which flows at a constant 52°F in their fish farming operation. Around an artesian well head they built a solar greenhouse to provide for their own year-round needs. To provide supplemental heat, the Harrimans pump the artesian water through 4'' PVC pipe laid in the gravel greenhouse floor. During the day the water may be warmed even more. It is routed through a three-ton Carrier Comfort Aire heat pump to provide 100% of the heating requirements for the Harrimans' 1000-square foot home. Water is expelled from the heat pump to the Harrimans' fish ponds. A booster pump off the greenhouse casing increases water flow from its natural 3 to 4 gallons per minute to 10 to 12 gallons per minute for greatest heat pump efficiency.

Operation
Operation of the system is amazingly simple according to Mrs. Harriman. The heat pump dumps its warm air directly into the house — no ducting is involved. Control is automatic. A thermostat in series with the heat pump maintains a constant comfortable temperature. The system requires very little maintenance.

Performance
The system has been in operation since October, 1977. ''It's the most fantastic thing,'' says Mrs. Harriman. It costs around $10 a month to run the pump(s) ''and that's all.'' Mrs. Harriman believes contrary to heat pump manufacturers that if you could provide enough volume, heat pumps would work well with water at 40°F. Refering to the casing laid in the greenhouse floor she adds, ''There's no better way to heat a greenhouse.''

Problems
The system performs beautifully, but the Harrimans were annoyed at price increases between planning and actualization of the project.

Modifications
None are planned nor envisioned.

Tips
Spend time scrounging and bartering before starting a project. Keep your plans flexible.

Financing
The project was carried out with the aid of a $4,000 state renewable energy grant.

Equipment
3-ton Carrier Comfort Aire heat pump

Budget

Equipment	
Artesian well-drilling, casing, valves	$1079.00
Heat pump-Carrier ''Comfort Aire''	1199.00
Bell & Gossett 1/12hp booster pump	77.16
Fiberglass vat-3x3x16'	225.00
	$2580.16

Plumbing	
PVC pipe - less 58.97 for domestic line	186.43
Galvanized pipe	34.65
Fittings (PVC and galv.)	253.54
PVC primer and cement	13.87
	488.49
Construction Materials	
Kalwall fiberglass	421.00
Galvanized tin sheeting	198.60
Valley tin	38.00
Fiberglass glazing (Sears)	95.98
Cement	160.00
Sand and gravel	52.00
Rebar	7.80
Plywood sheeting	192.10
2''x4''s and 2''x6''s studding	71.00
Insulation	50.00
Wiring-greenhouse and heat pump	172.88
Steel roofing	19.60
Copper pipe and wiring for heat pump	55.20
Bolts, nuts, nails, caulking	29.44
Freight-Kalwall	25.09
	$1588.69
Donated Materials (Estimated)	
Steel roofing	80.00
Tar paper	10.00
Pipe and fittings	10.00
Lumber	50.00
	$150.00
Domestic Hot Water	
PVC pipe and fittings for domestic water systems installed at same time	58.97
Domestic water pump	123.99
Pressure tank	90.00
	272.96
TOTAL	$5080.30

The Fowlkes House
Bozeman, Montana

Passive Solar Heat Collection and Trombe Wall Storage with Integrated Backup Wood Heat and a Solar Hot Water Preheater

Designer, Architect, Engineer and Builder - Charless W. Fowlkes

Microclimate

Recent measurements of solar intensity taken at a 60° angle in Bozeman suggest an average daily high 473 langleys in April and an average daily low of 280 langleys in January. Over the 30-year period, 1931 through 1960, temperatures in Bozeman averaged 43°F annually, with an average monthly high of 66.4°F in July and an average monthly low of 20.3°F in January. Through the period 1941 through 1970, Bozeman averaged 8165 heating degree days yearly. Precipitation averages 17.4 inches a year.

System Design

The design features 582 square feet of vertically standing south facing double-glazed glass, 480 square feet of which is backed by 20 water-filled, fiberglass tubes, each 16 inches in diameter and 17 feet long. The tubes hold about 200 gallons of water each and could provide three average days heat requirement in January. An insulating curtain with an R value of 20 is lowered on winter nights to lessen heat loss through the glazing. Backup heat is provided by a wood burning furnace with connected heat exchanger designed by Fowlkes. Air is used to form a heat exchange loop between the furnace and trombe wall. Three solar collectors with 50 square feet of glazing located on the porch of the Fowlkes' home supply heat to a 42-gallon preheat tank using an anti-freeze/water loop. The preheat tank is located between the cold water supply and a backup electric hot water heater. When the wood furnace is operating, hot air from the furnace flows around the tank which is located nearby. If the preheat tank temperature is less than the thermostat setting, the electric heater automatically provides backup heat.

Operation

Sunlight strikes the south facing glass wall and heat is stored in 20 water-filled fiberglass columns. A six-inch thick Polarguard (a continuous fiber material) filled insulating curtain is lowered on winter nights to reduce heat loss through the glazing. Although it can be rolled manually, the curtain is raised on a rod and stored above the water columns using a ⅓ horsepower reversible motor.

The furnace is a base burning configuration where the volatiles (smoke) must pass through a hot grate area while exiting from the firebox, thus promoting more complete combustion. Combustion air is preheated as it passes through the double bottom and double walled side of the furnace. Combustion gases from the firebox go into a tube type heat exchanger and are exhausted by a forced induction fan to the flue. Air is used to form a heat exchange loop between the furnace and trombe wall. A ¾ horsepower variable speed blower circulates air past the flue gas exchanger, then through a hot air duct to a distribution manifold along the base of the trombe wall. A cold air return manifold collects the air and leads it back to the blower. (See diagrams)

Performance

The home was first occupied in September 1977. The major portion of the construction of the insulating curtain, storage wall and wood furnace were carried out during the next three months. During 1978 from February 12 to November 11, the house was heated entirely by the sun. During the winter of 1978-79, slightly over one cord of wood was used for auxiliary heat. The first furnace fire was on November 11, 1978 and the last one on January 26, 1979, with a total of 16 fires during this winter. The inside temperature in this house average about 65-68 degrees. The temperature fluctuates about 10 degrees depending on the amount of solar radiation and outside temperatures. Overheating (contrary to common intuition) occurs not in the summer, but on warm sunny days in September and October. Last fall, this excess heat was circulated through the shop area using the wood furnace fan.

Problems

Charless Fowlkes still has his fingers crossed, but says he just hasn't had any yet. The system is fulfilling his highest expectations.

Modifications

Fowlkes used a non-standard glass size for his solar window. This caused some slight delays and perhaps added expense. He recommends that others use standard glass sizes on their design if at all possible.

Tips

"Get a good solar design with proven components. A contractor should then be able to handle the basic construction if he has a good set of plans."

Financing

"My bank was predictably cautious and I ended up with private financing, i.e., personal loans, etc." Fowlkes also received a $10,000 state renewable energy grant.

Equipment

Solar window - 1/8" tempered Herculite K double glazing

Thermal storage tubes - 20 fiberglass tubes, 16 inches in diameter, 17 feet long, from Spunstrand, Wallace, Idaho.

Insulating curtain - 4 layers of 10 oz. Polarguard, a continuous polyester fiber.

Outside curtain material - 6 oz. white dacron sailcloth panels arranged vertically for strength.

Inside curtain material - 6 oz. urethane coated nylon pack cloth.

Solar hot water preheat tank - Myers 42 gallon

Controls

A passive system generally requires human controls. Fowlkes may connect a sensor to the curtain drive motor, which would lower the curtain in winter when the sun becomes obscured for 20 minutes or more.

Monitoring

Fowlkes developed a computer based instrument station capable of reading up to 40 channels.

Insulation

Fiberglass R-20 walls, R-40 ceiling
Double or triple glazed windows all around

Budget

Trombe wall	$ 3,515.19
Solar window	4,614.60
Water heater	284.66
Wood system	1,702.33
Construction increments	1,228.30
	$11,345.08
Donated Labor	3,000.00
TOTAL	$14,345.08

The Mattson House
Bozeman, Montana

Active Air Collection and Rock Storage Integrated with Passive Design Features

Architect and Builder - George Mattson

Microclimate

Recent measurements of solar intensity taken at a 60° angle in Bozeman suggest an average daily high 473 langleys in April and an average daily low of 280 langleys in January. Over the 30-year period, 1931 through 1960, temperatures in Bozeman averaged 43°F annually, with an average monthly high of 66.4°F in July and an average monthly low of 20.3°F in January. Through the period 1941 through 1970, Bozeman averaged 8165 heating degree days yearly. Precipitation averages 17.4 inches a year.

System Design

The 3000-square foot house combines active solar air collection and storage with passive solar collection and storage. The 600 square foot active hot air collector is quite unique using uncoated pleated aluminum sheets — which bounce rays of the sun back and forth within the collector until a high percentage of solar energy is absorbed. The south facing collector panels are slanted at a 60° angle. Warm air is brought into the house through convection or with the assistance of a fan. Ducting also connects the collector panels with 21 cubic yards of rock storage and with a standard upright forced air gas furnace used to provide backup heat.

Passive features consist of an interior masonry wall running on an east-west line through the central portion of the house. South-facing clerestory windows above the collector panels allow sunlight to strike the wall and heat it. The thermal mass of the wall serves as a heat sink to passively balance daytime warming and night-time cooling. A wood stove located near the wall is the primary backup heat source.

The north and east exterior walls of the house are bermed with three feet of earth to increase its energy efficiency. Two 40-gallon preheat tanks for hot water are buried in the rock storage pile.

Operation

The active air system can operate in one of two modes. In one mode, interior air is drawn through the bottom of the panels, heated and convected directly into the house at the top of the panels. In the other mode, warm air is blown from the collectors into the furnace and then vented into the house through the furnace ducting system. The heated air can also be ducted into the rock storage for later use. During warm days, air in the collector is vented into the atmosphere through the top of the collector. A series of temperature sensitive heat sensors control four motorized dampers to direct the heated air to where it's needed. At night, warm air can be drawn from the rock storage through the furnace and vented throughout the house.

Performance

The system was completed in the summer of 1979 but the Mattson family had not yet moved in and no actual performance data was available before publication of this handbook. Mattson expects the system will provide 100% of his heating requirements down to -10°F. Below -10°F the wood stove or gas furnace will provide auxiliary heat.

Problems

There are no apparent serious problems evident or anticipated with the system at this time.

Modification

If George Mattson were to design and build his house over again, he says he would make it smaller, cut down on the number of difficult angles within the structure and make it more reliant on a passive solar system.

Tips

"Don't deliver gravel for rock storage in a cement truck — it gets dirty." "Go passive."

Financing

Mattson was a recipient of an $8,000 state renewable energy grant. The house was financed through conventional bank loans. The costs of the active and passive systems amounted to $13,700.

Equipment

The active system was provided and installed by Alternative Energy, Inc., 212 S. Main, Moscow, Idaho. Each panel measures 2'4" x 6'4" and is glazed with double strength glass. Panels arrived pre-assembled and duct work was fabricated on site.

Controls

Modular controls for the system were designed by Alternative Energy, Inc.

Monitoring

A computer based instrument station capable of reading up to 40 channels and developed by Bozeman engineer Charless Fowlkes, will be used to monitor the system.

Budget

Active System:	
Foundations and concrete block storage bin	$ 700
Concrete block storage ducts	74
Gravel heat storage, 22 cubic yards	134
Pre-heat water tank	85
Collector floor	100
Collector framework and enclosure	150
Collectors (600 sq. ft.), ductwork, glazing and controls by Alternative Energy, Inc.	8,980
Replace fan motor with outside motor	177
	$10,400
Passive System:	
Foundations and concrete block wall	$ 800
Stone veneer on storage wall	1,800
Windows, 140 sq. ft.	700
	3,300
TOTAL	$13,700

John Brown's Windborn Farm
Circle, Montana

Solar Greenhouse

Design - John Brown, Mgr.,
Windborn Farm, and Jim Baerg,
Baerg Builders
Builder - Baerg Builders,
Bozeman, Montana

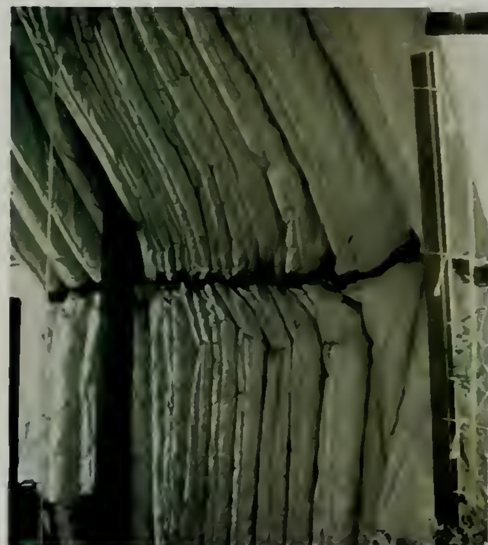
Microclimate

The site of the Windborn Solar Greenhouse is 10 miles north and 1.5 miles east of Circle, Montana, located in the east-central part of the state. McCone County is known for its high winds and severe winters. Winds average approximately 11 mph annually. Circle averages 8652 heating degree days yearly. Precipitation averages 11.33 inches a year. Measured at a 60° angle, in nearby Glendive (50 miles southeast), solar intensity peaks in April at 449 langleys a day and bottoms out at a daily average of 227 langleys in January.

Design and Operation

John Brown's 800 square foot Windborn Solar Greenhouse was designed to be thermally self-sufficient in the cold and windy McCone County area. The building is shaped as a sun scoop, buried in the ground with glazing primarily on the south. The design features heavy insulation, an insulating curtain for the south glazing and sufficient heat storage for nights and cloudy periods. The roof line is lower than most solar greenhouses to optimize thermal performance rather than providing light levels usually considered optimal for plant growth. A renovated 3000 watt Jacobs wind generator provides electricity for grow lights as well as for water pump, an exhaust fan, room lighting and some resistance heating.

Several methods are used to store heat. Twenty water-filled 55-gallon drums were painted black and lined up against the south glazing to provide passive heat absorption. One foot deep soil in growing beds, the greenhouse floor and a concrete back wall (insulated on the outside) also provide passive heat storage. Excess hot air from the peak of the greenhouse is drawn down by a DC powered squirrel cage fan into a two-foot by three-foot by forty-foot rock bed storage chamber located directly below the row of 55-gallon drums.



Surplus heat in the summer is vented to the outside. Intake vents on the bottom of the glass wall bring in cool air (cooling the oil drums also) replacing hot air which is vented out the top of the greenhouse. Three wind powered exhaust turbines which use no electricity draw out the hot air. A little-used electrically powered fan circulates the air on hot still days. In the summer of '78 the vents were left open day and night. The thermal mass effectively dampened out the temperature highs and lows so that no overheating occurred.

In addition, two home-built solar collectors with a thermosyphon anti-freeze heat exchange cycle provide hot water for a shower, sinks and for preheating irrigation water. A composting toilet, 500-gallon gravity feed water storage tank, well and pump, battery storage for the wind electric system, a root cellar and compost bins are also features of the greenhouse.

Problems and Modifications

The three exhaust turbines all broke down within a year. High moisture content of the exhaust air probably contributed, but the major problem occurred when the builders backfilled the back wall with original fill which happened to be an expansive type clay. After the first rain Brown noticed that the top of the back wall had been pushed in an inch. Baerg and Brown excavated along the side of the wall and attached concrete anchors to stop further movement. (When using earth sheltered construction techniques, be advised to take soil samples and consult with engineers to prevent similar accidents from happening. Corrections are expensive. See pages 13 and 14.)

The building was designed to shed prevailing northwest winter winds and reduce air infiltration with earth berming. Brown has experienced problems with snow blowing over the top of the greenhouse and around the end from the west. In the winter of '77-'78 snow piled up eight feet or higher on the southeast corner three times (the third time there was no room left to shovel the snow).

Financing

Brown was awarded one of the first state renewable energy grants, an amount of $12,500. Besides contributing some of the labor, Brown added another $2,000 out-of-pocket for material cost over original estimates. The well, pump, wind electric system, solar hot water system and excavating equipment were available to Brown and not included in his grant proposal.

Equipment

The most difficult equipment problem the builders faced was the question of insulating shutters. They investigated interior rigid, exterior rigid and finally settled on interior fabric curtains. The curtain is a sandwich of aluminized fabric, one inch of Polargard insulation and another layer of the aluminized fabric. The curtain is suspended on tracks and pulled aside during the day. Cost, space limitations, thermal performance, durability and ease and reliability of operation were important considerations.

Acquiring DC equipment for the fans and grow lights presented the builders with yet another dilemma. A selection of DC series motors of pre-Rural Electrification (REA) vintage were eventually found. None could be found in current production. They also had no luck obtaining DC timers, thermostats or growlights.

South glazing — double strength glass with an inner glazing of polyvinyl glazing
1800 watt/32 volt Jacobs Wind Electric with battery storage
5200 cfm/32 volt exhaust fan for no-wind periods

Monitoring

Temperatures on minimum/maximum indoor/outdoor thermometers are recorded daily. All electrical devices are metered and all produce is weighed. Charless Fowlkes of Fowlkes Engineering, Bozeman, under contract to DNRC, will monitor the building with a special 40 channel monitoring computer. Included in his data will be strip charts of insolation data and wind speed.

Insulation

Fiberglass - 9½ inches in ceiling
6 inches in frame walls
concrete walls and foundations are insulated on the exterior with 3 inches of styrene
floor is uninsulated.

Budget

Materials	$12,000
Wages	8,000
Overhead	1,000
Consultant	1,000
In-kind (from John Brown - Jacobs, tower, batteries, well, pump, solar hot water system, labor)	10,000
TOTAL	$32,000

System Design

"Successful greenhouse operation depends on three equally important matters. These are correct building design, successful gardening practices and social/economic considerations. Too many people are overly concerned with the techniques of building design. When I left Circle in the fall after completion of the structure, both John and I felt that the real work was just beginning. How do you control pests? How are optimum temperatures maintained? Do you grow a variety of plants for family consumption or are you to grow a few commercial crops and what are they? What are the biological implications of monoculture? Do you have adequate help to run the greenhouse? Who are your customers going to be? Are they a guaranteed source or are you going to have to spend harvest time scrambling for customers?

The growing project was organized to recycle soil and vegetable matter to conserve biological material and nutrients and to control pests. Three one-cubic yard compost bins used in series convert soil vegetable matter and animal and field waste from the farm into high quality fertilizer and soil. Earth worm beds provide the final breakdown of the waste material. Just as in his farming operation, John Brown has eliminated the use of energy intensive fertilizers, pesticides and herbicides. When I visited the greenhouse in May 1978, vegetables from the first major crop were heavily infested with pests: aphids, white flies. John reported that as the growing season progressed, the problems declined significantly. He attributes this success to the maturation of the soils and the balancing of the components in the greenhouse environment. No screens are used on the vents."

— Jim Baerg

Gary J. Franklin
Great Falls, Montana

Passive Solar Greenhouse Retrofit with Supplemental Wood Heat

System Design and Construction - Gary J. Franklin

Microclimate

Gary Franklin's house is located at 4428 6th Avenue South in Great Falls. Measured at a 60° angle, solar intensity peaks in April with a daily average of 478 langleys. An average of 170 langleys per day fall on Great Falls in January. Year round temperatures in Great Falls average 44.7°F with a high average of 69.4°F in July and a low average of 22.1°F in January. Great Falls averages 7652 heating degree days a year. Precipitation averages 14.1 inches yearly and the average mean wind speed is 13.1 mph.

System Design

After attending a solar workshop and doing some research on his own, Gary Franklin realized the orientation and configuration of his house offered good opportunities for a passive greenhouse retrofit. He decided an efficient wood burning stove could provide most of the supplemental heat that would be needed for both structures during cold spells.

Franklin estimates he spent 400 hours constructing the system. He attached a simple greenhouse structure to the south wall of his home. He mounted 144 square feet of commercially available double fiberglass glazing in extruded aluminum frames on the greenhouse's south wall. Kalwall's Sun-lite glazing panels were chosen over glass because of their greater strength, lighter weight and easier installation, even though their cost was slightly more than the originally planned glass. Thermos Space Blankets are used to insulate the structure at night and on cloudy days. Heat is stored in 12 50-gallon water filled drums which Franklin salvaged from a local dry cleaning plant. Adjustable floor and ceiling level vents were added to the wall between the living quarters and greenhouse to allow for natural heat flow into the house.

A fan was installed in the window between house and greenhouse to draw warm air into the greenhouse from the stove when needed. An efficient wood burning stove is located near the south wall in the house. The greenhouse also provides a year round source for fresh vegetables.

Operation

As with most passive systems, operation is manual and fairly simple. On cold days, the greenhouse is opened to the house to provide warmth. Usually the wood burning stove is only needed on exceptionally cold nights. The Thermos Space Blankets are lowered at night and during cloudy periods to lessen heat loss to the outside.

Performance

Franklin reports the system worked well during the winter '77-'78. Backup natural gas heating never exceeded $30 month when the system was in use. Without the system, heating the Franklin home in winter nears $70/month. Without reimbursement for wages, cost of the system was $4,202.15. Assuming a savings of $220 per year in heating costs and $550 savings in food costs, as estimated by Franklin, payback would be complete in 5.7 years. ($4,202.15 ÷ ($220 + $520) = 5.7) Franklin estimates paying standard wages for all the work done would bring the payback to 11 years.

Other factors which would bear weight on this analysis include: The cost of obtaining firewood (whether you gather it yourself or buy it from a dealer); yearly maintenance costs on the stove (chimney sweeping — again whether you do it yourself or have it done); initial costs of soil, fertilizer and seed for the greenhouse and other hardware for its operation; maintenance costs on the greenhouse; escalating costs of food and natural gas.

Problems

None noted

Modifications

Possible energy savings could have been experienced by setting the greenhouse deeper in the ground and using a more efficient insulating curtain.

Tips

"Take the time to read as much as possible on the state of the art, attend available workshops and talk to everybody involved in projects such as this." But . . . "GET STARTED! Everybody is talking about alternate energy, but very few seem to be doing anything about it."

Financing

State renewable energy grant for $5,000

Equipment

Glazing - Sun-lite Glazing Panels, Kalwall Corp., Manchester, N.H.
Stove - Jotul

Monitoring

1. Daily reading and recording of greenhouse temperatures on max/min thermometer.
2. Daily reading and recording of outdoor and indoor temperatures.
3. Recording of brand names and types of seeds used in greenhouse to determine which species provide best yield in this environment.
4. Maintaining costs incurred in obtaining firewood
5. Maintaining record of natural gas consumption and cost.

Insulation

Walls, R-28; ceiling, R-33.

Budget

Labor	$ 923.79
Materials	4,180.15
Equipment rental	22.00
TOTAL	$5,125.94

The Bass Creek Commune
Stevensville, Montana

Integrated Solar Wind and Wood System

Design: Bass Creek Solar and Wind
Architecture: Paul Power and Charles Rial
Engineering: Paul Power and Thomas Power
Builder: Bass Creek Commune

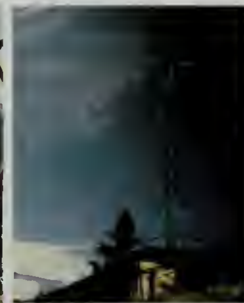
Microclimate
The site which overlooks the Bitterroot Valley is located on a south facing hillside 800 feet above the floor of Bass Creek Canyon. Located slightly below a ridge, it is also protected from prevailing westerly winds by a stand of ponderosa pines. The site is well above the winter ground floor and the site is often above the clouds which cover the valley during fall and winter. During the last seven years, the growing season at the site has been two to three weeks longer than on the valley floor. The wind machines are on 50 foot towers 150 feet from the building site and sit on a ridge at the canyon mouth, which channels wind, increasing its velocity. Weather data available from nearby Stevensville indicates an average of 7,668 heating degree days a year and an average yearly temperature of 44.6°F. January temperatures average 23°F, while July temperatures average 66°F. Precipitation averages 12.7 inches annually. Solar insolation data for the general area is not available at this time.

System Design
The Bass Creek Commune is a cooperative living and working collective organized in 1968. The massive building featured here houses studio and workshop space for the group. Three renewable energy systems, solar, wind and wood, are integrated to provide the structure with space heat, domestic hot water and electricity.

The solar portion of the design includes two passive systems. The south facing wall of the structure contains 430 square feet of double glazed windows. All windows are insulated by curtains or shutters with R values varying from 3 to 10. Thermal mass for the passive system is a 30' x 30' x 6'' concrete slab.

A homebuilt, 600 square foot solar air collector uses a convective loop to collect and store heat which eliminates the need for fans. Heat is stored in 1000 cubic feet of 4 to 6 inch rock in the bottom of the structure. The collectors are double glazed with double strength glass and use a six layer expanded metal lath absorber plate with 11 inch channels.

The wind system features two rebuilt 3 Kw Jacobs wind generators acquired in Malta. The generators charge 19 195 ah (20 hr) batteries. When fully charged, the electricity is used to heat 250 or 500 gallons of water stored within the rock bins.



Auxiliary heat is supplied by a homebuilt wood furnace with outside combustion air to completely burn wood between 2000 to 2500°F. A 25 foot forced air flue facilitates heat transfer. The furnace is located in the rock bin and the flue runs along the bottom of the bin.

Operation
The convective loop solar system is equipped with manually operated dampers to prevent reverse convection.

A loading switch automatically regulates battery charging in the wind system. A manual switch operates the immersion heaters.

Fires are started simultaneously in the stack and fire box in the auxiliary wood heat system. The forced draft fan is switched manually.

Performance
The wind system has performed exceptionally well. The performance of the solar and wind system have been good but both will be thoroughly instrumented and monitored to check efficiency at some future date.

Problems
Designing an effective damper system at the collector/rock bin interface offered particular problems. The final design swings insulated portions of the collector back over inlet and outlet ducts. This solution provides both dampening and venting.

Building maintenance above the collectors could prove to be a problem. The building rises 50 feet above the collectors. The builders hope the structure will remain virtually maintenance free.

The design of the flue/furnace interface also posed potential problems. Differential expansion would tear a fixed flue out. Leaks would draw heated air out of the storage and up the chimney. The final design offered a low expansion steel collar and flexible refractory.

The possibility of flue burnout presented a serious problem because of almost impossible replacement. The flue, two 12'' diameter culvert pipe, is fitted over a steel collar with 1000 cfm of air fan-forced over the first four to six feet of pipe.

Modifications
Kalwall was to be used as collector glazing, but double strength glass was substituted because of its lower cost and availability.

The collector absorber plate was changed from looped insect screen to layered metal lath to reduce the pressure drop over the 16' channel.

It was hoped the wind plant would provide enough power to heat 1000 gallons of water for space heating, but 1½ years of operation indicates this is not possible. The solution has been to heat less water to a higher temperature.

Tips
''Keep it flexible''

Financing
About $12,000 came from the SB86 program which financed part of the heating system. The structure and remainder of the system were financed through conventional loans.

Equipment/Installation
The wind plants are 30 year old recycled Jacobs. Everything else was fabricated on site.

Controls
All controls are now manual except for the wind system. A thermostat will be installed on the furnace which will activate the fan automatically.

Monitoring
In place or planned is an anemometer with a strip chart recorder, a DC KWh and amp-hour meter, a pyranometer with recorder, two or three temperature probes with recorder and interior thermometers.

Insulation
The collectors have 12'' of fiberglass in the base and 6'' on the sides sandwiched between thermoply. The rock bin has 12'' of fiberglass all around with thermoply on the inside; the building has 6'' of fiberglass in the floors and walls and 10'' in the roof. The garage is insulated from the rest of the building.

Budget
Grant-Related Expenditures

Solar Collectors	$ 3,477.85
Heat Storage & Distribution	4,738.99
Wind System	4,153.89
Monitoring	2,356.31
Administration	536.79
Night Curtains	610.00
TOTAL	$15,873.83

APPENDIX A
HEAT FLOW CALCULATIONS

The rate of heat flow (the U-value) is expressed in BTU per hour, per square foot, per degree of temperature difference between the inside and outside surfaces (BTU/sq. ft./hr./°F). The smaller the U-value the better the insulating value.

For example, to determine the U-value of a wall first calculate the total R value (R_t) by adding the R values of the materials composing the wall. Below are the R factors for the individual components of a suburban house wall with a typical amount of insulation.

	R factor
Exterior/air film	0.17
Wood siding (1'' × 8'')	.78
1'' air space	.90
2½'' fiberglass insulation	7.80
½'' drywall	.45
Inside still air	.68
Total of R Factors, R_t	**10.78**

The total R value is 10.78; the U-value is its reciprocal, 1/10.78 = 0.093 BTU/sq. ft./hr./°F. The U-value expresses the heat flow in BTU through each square foot of wall for each degree of temperature difference between the inside air temperature and the outside air temperature. To calculate the rate of heat flow through the entire wall, the total wall area and the difference between the inside and outside temperatures must be known. The weather bureau has established standard design temperatures which designate the lowest outside temperature of the year for every major city in Montana. The temperature differential can then be derived from the standard design temperature by subtracting the design temperature from a designated indoor temperature of 70 degrees F. If this wall were located in Helena, then the standard design temperature would be -10 degrees F and the temperature differential would be 80 degrees F [+70°F − (-10°F)].

If the wall mentioned above, with a U-value of .093, had an area of 900 square feet (excluding doors and windows, studs, headers, and plates), the heat flow per hour could be calculated as:

Heat flow = Area (900 sq. ft.) × Temperature differential (80°F)
× U-value (.093 BTU/sq. ft./hr./°F)

900 sq. ft. × 80°F × .093 BTU/HR/sq. ft./°F = 6696 BTU/HR

A 900 sq. ft. wall in Helena with U-value of .093 loses heat at design conditions at the rate of 6696 BTU/HR. This type of calculation assumes that the temperature differential is constant throughout the wall height; it also assumes unfluctuating heat conditions as well as a homogenous wall section. Adjustments should be made to the heat flow for areas of the wall which are occupied by structural, electrical, and mechanical elements. In some cases, this could be in excess of 30 percent of the wall. The U-value in these areas would be greater than the one calculated—i.e., more heat would be lost through the wall. These considerations also apply to the roof area and floors.

APPENDIX B
CALCULATING HEAT LOSS

When considering a renewable energy system, it is necessary to calculate the rate of heat loss from the building; the rate at which it loses heat is the rate at which heat must be supplied to maintain a relatively constant temperature.

To calculate heat loss, first determine the R-values of the walls, ceilings, floors, windows and doors as discussed in Appendix A. Second, calculate the area in square feet of the building's structural components. Third, determine the design temperature for the area in which the building is located (Table B-1).

Two values are listed for design temperatures in Table B-1. The 99 percent value means that the temperature was lower than the listed value 1 percent of the time for the months of December, January, and February for some previous long term recorded period. The 97½ percent value means that the temperature was lower 2.5 percent of the time or 54 hours. Selecting the 97.5 percent value to size a heating system would mean that a building will be a little colder than is perhaps ideal for a few hours (probably at night) during the year. However, a furnace would then be more efficient because of its smaller size.

Fourth, compute the temperature differential, which is the difference between the inside temperature and the (outdoor) design temperature. For the below grade portion of the structure, the temperature difference is the difference between the below grade indoor temprature and 40°F (average ground temperature for Montana). Fifth, apply the above information to the following formula: unit's area × unit's U-value × temperature differential, which equals the heat flow through each unit's structural components. Sixth, total the heat flow through each component to determine the total heat loss per hour through the building materials. Finally, add the heat loss due to infiltration which can be derived from the air-change method in Table 1-1, page 8.

Heat loss calculations are performed for extreme temperature conditions and are utilized to obtain the correct size heating plant to heat a house under severe winter conditions. Constructing a solar system to meet the heating requirements of a house during the most extreme winter temperatures is simply uneconomical—particularly when there is a standby furnace. In fact, enlarging the solar system to handle those few times each winter when the temperature is lower than the design temperature could easily quadruple the cost of the system. A solar heating system which is practical will be designed to provide the heat required, or some percentage thereof, during average heating conditions during the winter months. But the above calculations are still necessary to determine average heating requirements.

Table B-1. Design Temperature for Montana Cities*

City	Design Temperature (°F) 99%	97½ %
Billings	-15	-10
Bozeman	-20	-14
Butte	-24	-17
Cut Bank	-25	-20
Glasgow	-22	-18
Glendive	-18	-13
Great Falls	-21	-15
Havre	-18	-11
Helena	-21	-16
Kalispell	-14	- 7
Lewistown	-22	-16
Livingston	-20	-14
Miles City	-20	-15
Missoula	-13	- 6

*Latest ASHRAE values (ASHRAE Fundamentals, 1977) Dry Bulb 97½% values

"Degree Days" are used to estimate these average heating requirements. A degree day accrues for every degree the average outside temperature is below 65°F for a 24-hour period. Days with average temperatures above 65° are not counted. For example, if the outside air temperature is a constant 30°F over a 24 hour period, then 35 degree days accrue. It is assumed with the Degree Day method that if the outside temperature is 65°F or higher no heating requirements exist to keep the inside temperature of the home at 70°F.

Using the Degree Day method, the number of BTU required to heat a given structure in a given locality for a given month can be estimated. And although it is an averaging system, it is extremely practical and is widely used by heating contractors. Table B-2 lists the Degree Days for various Montana locations.

After the design temperature requirements of a building have been calculated, it is a simple matter to convert that BTU figure into a figure usable with the Degree Day method.

Say that a house has a calculated heat loss of 30,060 BTU/hr at a design temperature of -10°F. In a 24 hour period at that temperature, the house will require 721,400 BTU (30,060 × 24) to maintain an inside temperature of 70°F. Between the base 65°F and -10°F, there are 75 Degree Days. Dividing the 24 hour requirement of 721,400 BTU by 75, a requirement of 9620 BTU for each Degree Day is obtained. Therefore, the house would be designated a 9620 BTU/Degree Day house which means that if the outside temperature were 64°F (one degree below the base of 65°F), it would require 9620 BTU to heat the home for 24 hours.

Table B-2. Total Average Heating Degree Days for Various Montana Locations (base 65°F)

Western	
Bigfork	7211
Darby	7361
East Anaconda	8414
Fortine	8424
Hamilton	7187
Haugan	8152
Heron	7738
Kalispell	7842
Libby	7443
Missoula	7931
Philipsburg	8856
Saint Ignatius	7197
Seeley Lake	8773
Stevensville	7668
Summit	10628
Superior	7203
Thompson Falls	6684
Trout Creek	7648
West Glacier	8465
Southwestern	
Belgrade	8686
Boulder	8572
Bozeman	8165
Butte	9719
Dillon	8354
Ennis	8020
Hebgen Dam	10574
Lima	9567
Norris	6970
Trident	7393
Virginia City	8489
West Yellowstone	10986
Wisdom	10824
North Central	
Babb	9327
Big Sandy	8219
Browning	9056
Chinook	8465
Choteau	7954
Conrad	8142
Cut Bank	9033
Dunkirk	8998
Fairfield	7835
Fort Assinniboine	8678
Fort Benton	7657
Harlem	8729
Havre	8687
Simpson	9263
Turner	9199
Valier	8380
Central	
Augusta	8000
Cascade	7324
Flatwillow	7678
Gibson Dam	8591
Grass Range	7765
Great Falls	7652
Harlowton	8117
Helena	8190
Holter Dam	6802
Lewistown	8586
Melstone	7325
Moccasin	8398
Roundup	7015
Troy	8129
Townsend	8227
White Sulphur Spgs	8792
Winifred	8288
South Central	
Ballantine	7202
Big Timber	6766
Billings	7265
Bridger	7036
Busby	8037
Columbus	7331
Cooke City	11316
Crow Agency	7436
Hardin	7530
Huntley	7535
Livingston	7593
Mystic Lake	8601
Rapelje	7727
Red Lodge	8501
Wyola	7468
Northeastern	
Circle	8652
Culbertson	9163
Fort Peck	8427
Glasgow	8969
Glendive	7774
Haxby	8337
Jordan	8099
Medicine Lake	9225
Poplar	8823
Savage	8473
Scobey	9069
Vida	8672
Westby	9573
Southeastern	
Broadus	7871
Colstrip	7441
Ekalaka	8163
Mildred	8073
Miles City	7889
Plevna	8543
Rock Springs	8401
Wibaux	8892

SOURCE **Climatological Data**, Volume 81, No. 7, National Oceanic and Atmospheric Administration, Asheville, NC

A simpler method for converting BTU calculations into a Degree Day calculation is provided by the chart below: Multiply the total BTU loss per hour by the appropriate conversion factor and the result will be in BTU/Degree Day.

CONVERSION FACTORS FOR HOURLY BTU HEAT LOSS TO BTU/DD SIZE

Design Outside Temperature (°F)

	-30	-20	-10	0
Conversion Factor	.25	.28	.32	.37

The following example is a calculation for the heat loss of a building with a main floor, 30' × 40' with an 8' ceiling and a daylight basement with the same dimensions.

Assume an indoor temperature 70°F and outdoor design temperature -21°F (Helena).

Main floor 30' × 40', 8' ceiling

Ceiling area: (30') (40') = 1200 sq. ft.

Outside window area = 120 sq. ft.

Outside door area = 21 sq. ft.

Wall area = 2(30)(8) + 2(40)(8) − 120 − 21 = 979 sq. ft.

Daylight Basement 30' by 40', 8' ceiling, 4' concrete wall (foundation)

Floor slab area = (40')(30') = 1200 sq. ft.

Outside window area = 80 sq. ft.

Outside door area = 21 sq. ft.

Concrete wall area = 4 (30)(2) + 4(40)(2) = 560 sq. ft.

Studwall area = 560 − 80 − 21 = 459 sq. ft.

With the areas known, calculate the total R values. Assume R-19 wall, R-38 ceiling, 1'' styrofoam on the concrete, R-2.2 for the doors, R-1.35 windows and ½ air change per hour.

$$\text{Heat Loss, concrete wall} = \frac{560 \text{ sq. ft. } (70°F - 40°F)}{(5 + 5)\ \frac{hr - ft^2 - °F}{BTU}} = 1680 \text{ BTU/hr}$$

$$\text{Heat Loss, floor slab} = \frac{1200\ (70 - 40)}{10} = 3600 \text{ BTU/hr}$$

$$\text{Heat Loss, stud walls} = \frac{(979 + 459)\ [70 - (-21)]}{19} = 6887 \text{ BTU/hr}$$

$$\text{Heat Loss, ceiling} = \frac{1200\ [70 - (-21)]}{38} = 2874 \text{ BTU/hr}$$

$$\text{Heat Loss, windows} = \frac{(120 + 80)\ [70 - (-21)]}{1.35} = 13{,}481 \text{ BTU/hr}$$

$$\text{Heat Loss, doors} = \frac{(21 + 21)\ [70 - (-21)]}{2.33} = 1640 \text{ BTU/hr}$$

$$\text{Heat Loss, infiltration} = \underbrace{(8)\ (1200)\ (2)}_{\text{total house volume}}\ \underbrace{(½)\ \frac{ft^3}{hr}}_{\text{air change/hr}}\ \left(.015\ \frac{BTU}{ft^3 - °F}\right)\ [70 - (-21)] = 13{,}104\ \frac{BTU}{hr}$$

TOTAL HEAT LOSS = 43,266 BTU/hr for the 1200 ft² house with a daylight basement for an outdoor temperature of −21°F

Then in terms of Degree Days

$$\frac{43{,}266\ \frac{BTU}{hr}}{[65 - (-21)]\ °F}\quad 24\ \frac{hr}{day} = 12{,}074\ \frac{BTU}{DD} \text{ house}$$

For January, the number of Degree Days in Helena is 1438 and

$$\text{total heating load for January} = (12{,}704\ \frac{BTU}{DD})\ (1438\ DD)$$

$$= 17{,}326{,}746 \text{ BTU}$$

$$\text{and for the year} = 12{,}704\ \frac{BTU}{DD}\ (8129\ DD = 1{,}032{,}708{,}160 \text{ BTU}$$

If electrical heat is used at .0246 $/kw-hr (1978 MPC rate) then the yearly bill would be:

$$\text{yearly heating bill} = \frac{1{,}032{,}708{,}160 \text{ BTU}}{3412 \text{ BTU/kwh}}\quad \frac{.0246\ \$}{kw\text{-}hr}$$

$$= \$744.57$$

APPENDIX C
MEASURING THE AVAILABLE SOLAR ENERGY

Solar radiation is composed of direct beam radiation (which casts a shadow) and diffuse radiation (which does not). The most commonly measured value of solar radiation is total (direct beam and diffuse) hemispheric radiation on a horizontal surface recorded either hourly or daily using an instrument called a pyranometer.

A pyranometer measures the intensity of solar radiation (both diffuse and direct), which is usually calculated in langleys: one langley equals one calorie/cm². Three hundred fifty langleys/day is the average of solar radiation for Montana. The insolation rate (the rate of delivery of solar radiation per unit surface area) does not remain constant throughout the year for a horizontal surface, but varies from a low of 114 langleys/day in December to a high of 633 langleys/day in July. Table C-1 shows the monthly variation in insolation for Great Falls.

Table C-1. Solar Insolation on a Horizontal Surface, Great Falls, Montana (langley/day)

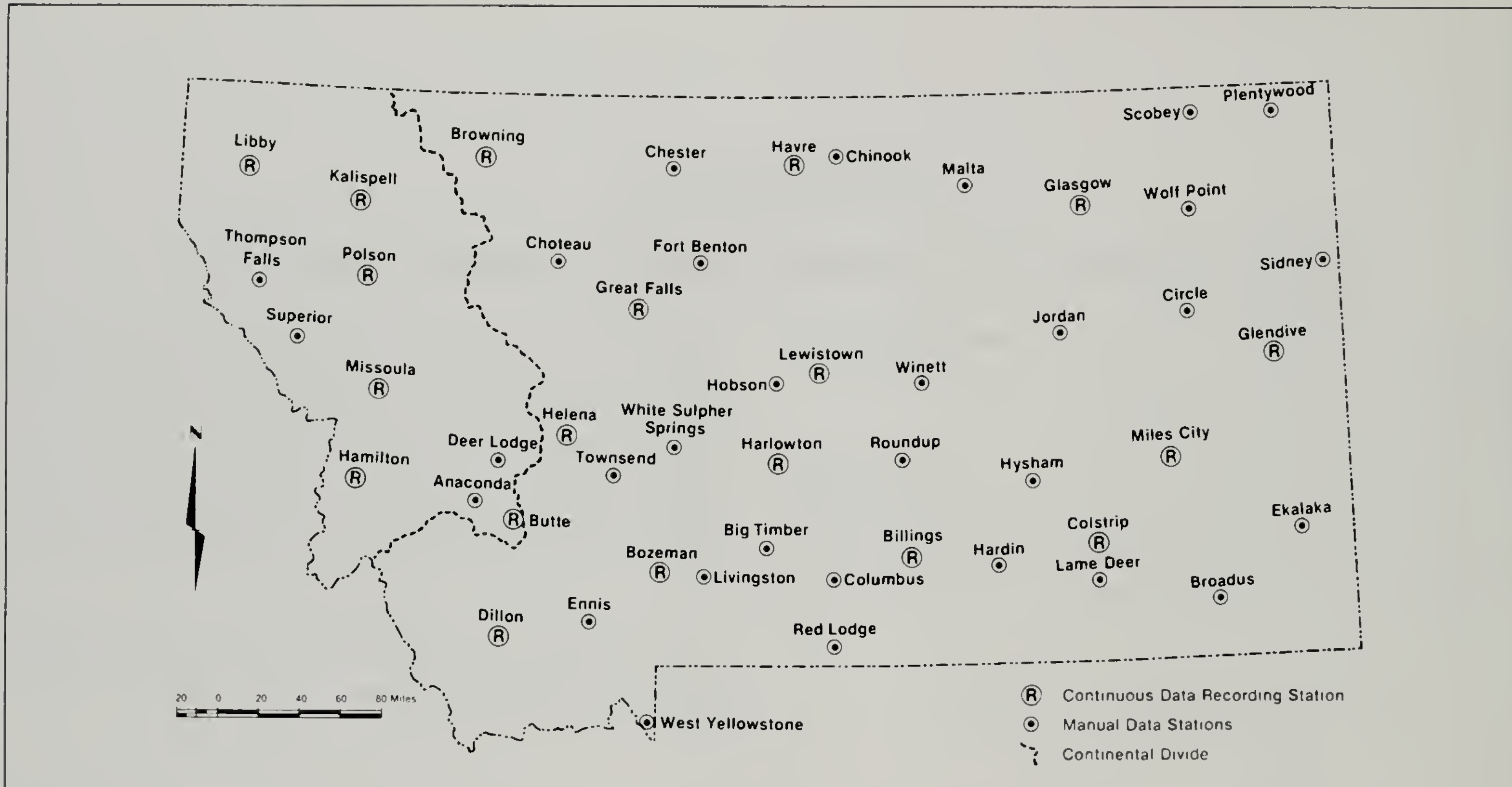
January		152
February		260
March		396
April		457
May		547
June		591
July		634
August		517
September		392
October		246
November		137
December		112
Yearly Average	=	**370**

It is valuable to break down the amount of solar energy incident on a site into monthly or even weekly averages, for such figures can then be used, along with climatological records and knowledge of system performance, to design a solar heating system which is adequate, but neither too large and expensive nor inadequate for a particular structure. Nationally, the weather bureau has data for total hemispheric radiation on a horizontal surface recorded for various places and varying lengths of time. In Montana these stations are at Great Falls and Glasgow. Only at Great Falls are data provided for hourly intervals—Glasgow records only total daily insolation. One problem with the data is inaccuracy, which is estimated to be ±5 percent for accurately calibrated instruments and ±10 percent for those less carefully calibrated.

In 1976, Charless Fowlkes of Fowlkes Engineering in Bozeman obtained funding from the State of Montana for an insolation monitoring program. By January, 1977, 30 instruments were located in public high schools (see Figure C-1) across the state and were continuously recording insolation.

This monitoring program suggests that the amount of solar energy available around the state varies considerably. Measuring this variation is necessary because a solar heating system that is not practical in one part of the state may be an economical heat source in another part. Cloud cover, precipitation, and air pollution affect the amount of radiation received. Although Fowlkes' data give Montanans better information than was available in the past and make estimation of solar energy received at a particular site more accurate, it is still advisable to measure the energy on each particular site.

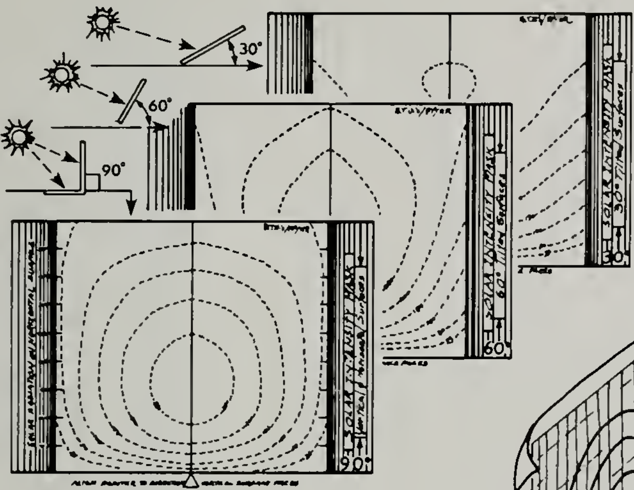
Another method (see pp. 89-92) for computing the amount of insolation a particular site receives, one that does not rely upon instruments to take light intensity readings, entails using the sun chart along with solar intensity masks. With this method, intensity readings can be taken on the horizontal and vertical as well as on a 30° and a 60° surface.

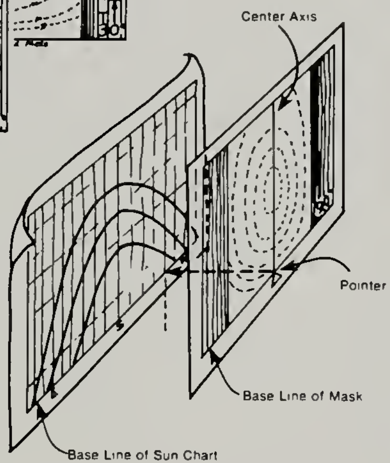


Source. Charless Fowlkes, Bozeman, Montana

Once the monthly insolation rate over a year is determined (remember daily or hourly insolation data are even more helpful), the size of the system needed to provide for a given percentage of space or water heating requirements can be calculated. For example, in Billings, the average daily insolation for February, 1977, was 66 percent of the total possible insolation for February at that location. Since clear day insolation values in Montana average 6.7kw-hr/m², or 2200 BTU/ft², then the average daily insolation at Billings would be approximately .66 × 6.7kw-hr/m² which equals 4.4kw-hr/m² or 1452 BTU/ft². If the building's daily heat load in February is 350,000 BTU, then all the radiation falling on approximately 240 square feet of surface would need to be collected.

This assumes that the solar system not only can collect all the radiation falling on 240 square feet of surface but that it also converts all of the radiation into usable heat (100 percent efficiency). But, the conversion process generally occurs at far less than 100 percent efficiency. Consequently, any system that is designed to meet 100 percent of a building's space heating requirements would have to collect the radiation falling on a surface far greater than 240 square feet. Such a system would be prohibitively expensive. In Montana, it is reasonable to design a system which will provide about 50 percent of a structure's space heating requirements. Two hundred eighty square feet of collector provides 50 percent, but it takes 700 square feet for 100 percent solar heating—more than twice the area.





ALIGNMENT EXAMPLE:

Vertical Surface facing 45° west of south:

Set the pointer on the intensity mask to line up with 45° west on the base-line of the Sun Chart. Be sure that the base lines of both sheets are in line.

—Mask and Sun Chart are now aligned to read solar intensity values.

In the design of solar heating and cooling systems, it is important to know the amount of thermal radiation (sun's heat measured in BTU's) that strikes a surface at some particular time of the day, hour, or daily or monthly totals. This can all be determined by the use of the solar intensity masks (to be found on the following pages) which fit over and are used in conjunction with the Sun Chart (to be found in Appendix E). The mask marked "90°" is for vertical and horizontal surfaces, mask "60°" for inclined surfaces of 60°, and likewise, mask "30°" for inclined surfaces of 30° (as measured from the horizon).

The solar intensity masks have a center axis and base line which are used for alignment with the Sun Chart. To align the mask for a particular surface, determine the direction the surface is facing and set the center axis of the mask on the bearing angle (the direction the surface is facing) of the Sun Chart. Keep the base line directly over the base line of the Sun Chart. You are now ready to determine the solar intensity values for that surface.

HOURLY TOTALS

To determine the clear day hourly totals of heat energy striking a surface:

1)—Select the proper mask based on the surface slope.

2)—Align the mask on the Sun Chart based on the orientation of the surface to the east or west of south.

3)—Select the month when you want the reading and use that sun path to read the values.

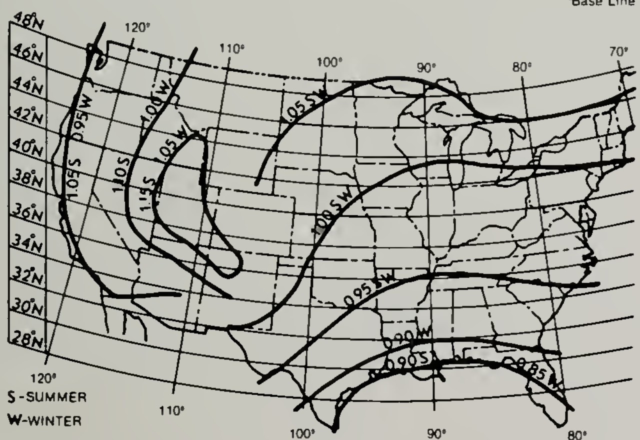
4)—Select the hour and month in which you want the reading: the intersection of the hour line and the sun path will locate the position of the sun. Read the number of BTU's for that sun's position from the radiation mask - if the point where you want the reading falls between radiation lines, interpolate to find the value.

NOTE: This clear day number needs to be adjusted depending on your location in the U.S. Find the line which is closest to your area on the map below. S is for summer adjustment numbers, and W is for winter adjustment numbers. Multiply the clear day totals from the mask by these adjustment numbers.

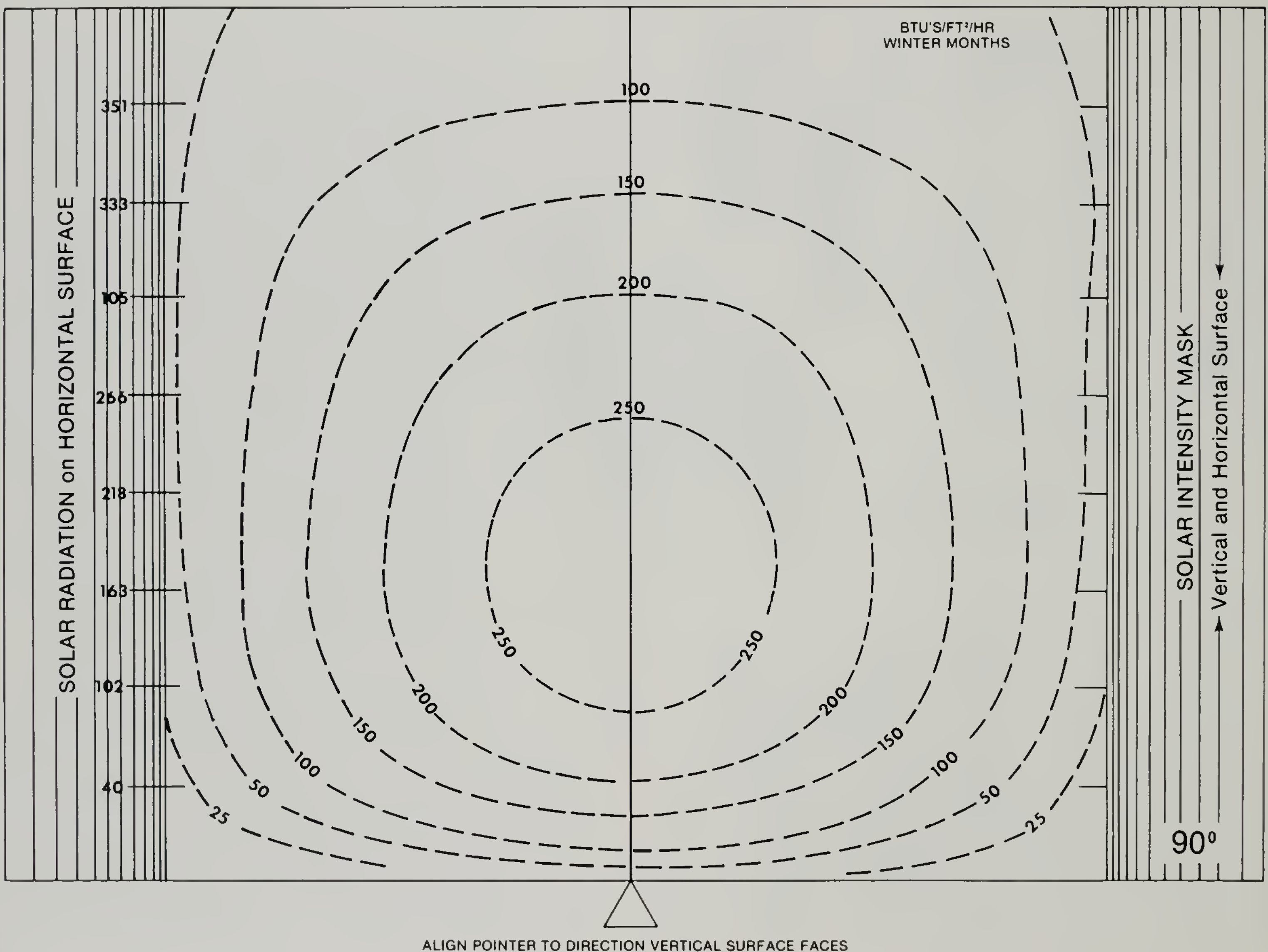
DAILY TOTALS

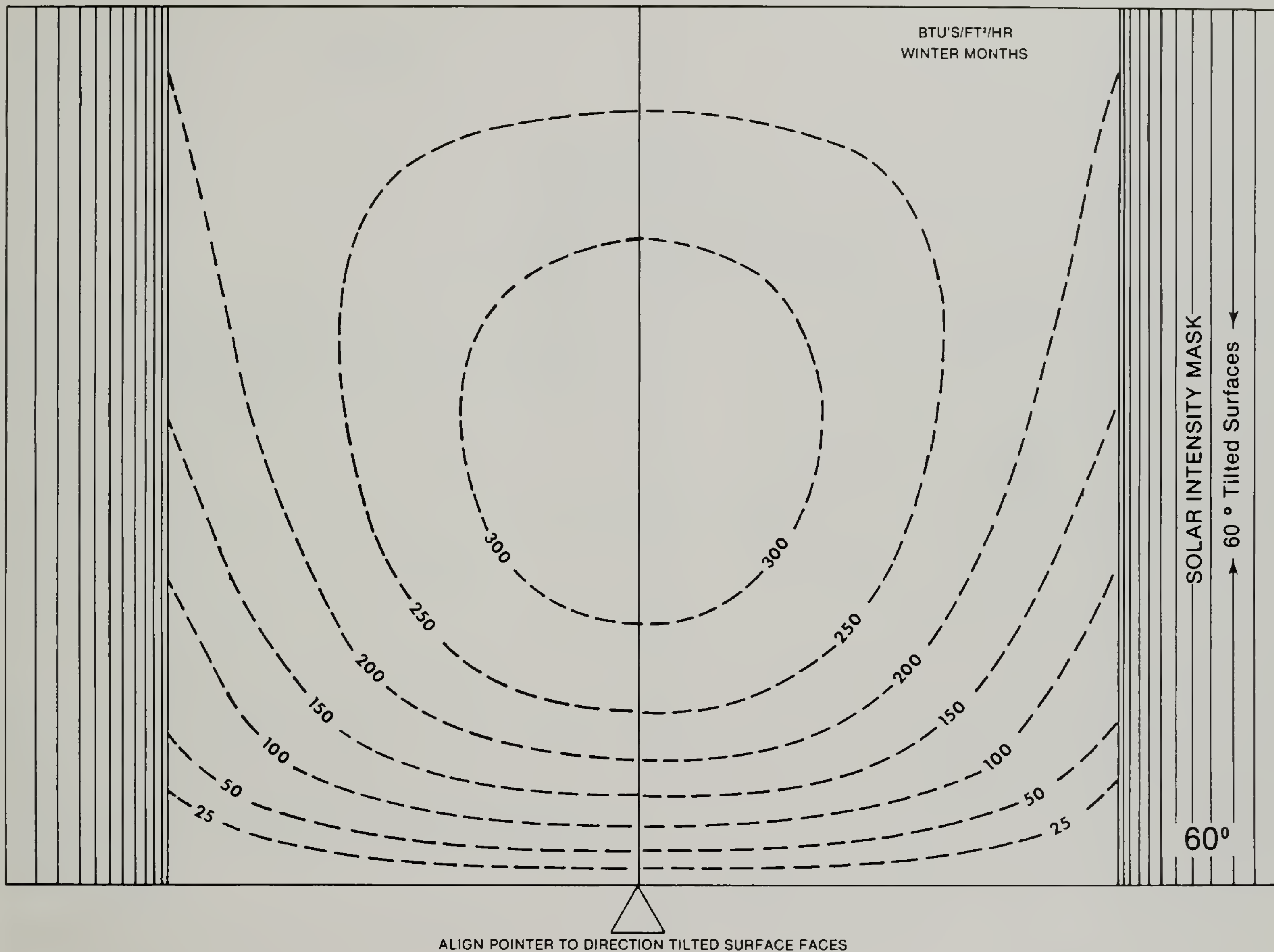
To determine the total daily amount of heat energy striking a surface:

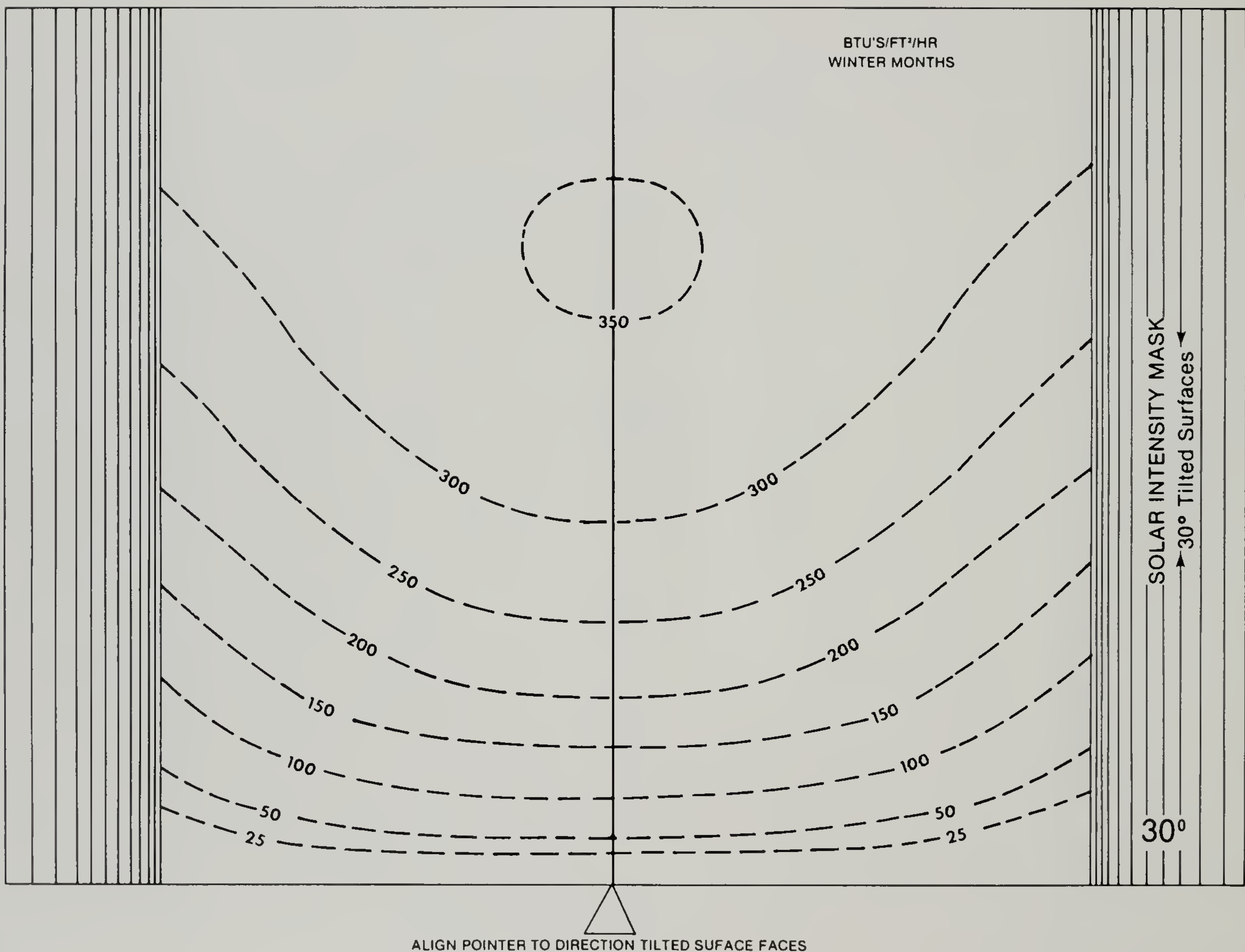
—Simply follow the procedure for the hourly totals for each hour of the day and total these to get the daily total. If the hourly totals have not been adjusted for your area, then adjust the daily total by multiplying it by appropriate adjustment factor from the map.



Source: **Sun Guida and Calculator**, Edward Mazria, Eugene, Oregon


BTU'S/FT²/HR
WINTER MONTHS
SOLAR RADIATION on HORIZONTAL SURFACE
351
333
105
266
218
163
102
40
100
150
200
250
250
250
200
200
150
150
100
100
50
50
25
25
SOLAR INTENSITY MASK
Vertical and Horizontal Surface
90°
ALIGN POINTER TO DIRECTION VERTICAL SURFACE FACES


BTU'S/FT²/HR
WINTER MONTHS
300
300
250
250
200
200
150
150
100
100
50
50
25
25
SOLAR INTENSITY MASK
60 ° Tilted Surfaces
60°
ALIGN POINTER TO DIRECTION TILTED SURFACE FACES


BTU'S/FT²/HR
WINTER MONTHS
350
300
300
250
250
200
200
150
150
100
100
50
50
25
25
SOLAR INTENSITY MASK
30° Tilted Surfaces
30⁰
ALIGN POINTER TO DIRECTION TILTED SUFACE FACES

APPENDIX D
F CHART ANALYSIS

Using this simplified f-chart, Figure D-1, the fraction of annual heating load supplied by a solar system with an overall efficiency of 30 percent, whose collectors are oriented due south and mounted at an optimal tilt of 62° can be calculated from the fraction of the January heating load that system will provide. The fraction ot January heating load is computed according to the formula

$\frac{A \times S}{L}$ where

A = solar collector area (ft^2)

S = January solar radiation on a horizontal surface ($\frac{BTU}{ft\ month}$)

L = January building heat load ($\frac{BTU}{month}$)

f = fraction of the annual heating load supplied by the solar system

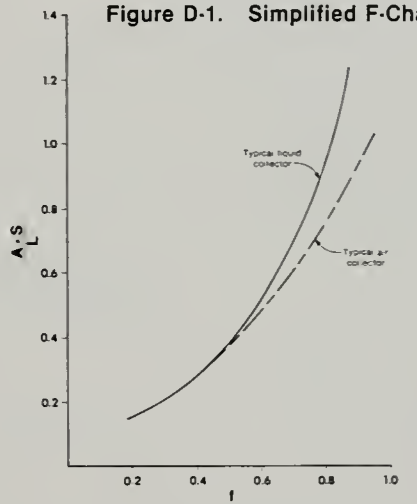
The curves in the graph were generated from computer simulations and experimental data for a collector at 15° atitude facing directly south.

For example, suppose a home is located in Great Falls and the January heat load is 15,000,000 BTU/month. There is space tor 600 ft² of air collector mounted at a 60° slope from the horizontal and oriented due south, which is the optimum slope and orientation. To calculate what fraction of the heat load that 600 square feet of collector will supply, calculate $\frac{S \times A}{L}$

To derive S use the insolation chart on page 87. For Great Falls

S = (152 langley/day) × 31 days (January)

Figure D-1. Simplified F-Chart



Source Mechanical Engineering Department, Montana State University, Bozeman, Montana, 1978.

To convert langley/day to $\frac{BTU}{ft^2\text{-day}}$ multiply by the conversion factor, 3.7 $\frac{BTU}{langley\text{-}ft^2}$

$$152 \text{ langley/day} \times 3.7 \frac{BTU}{langley\text{-}ft^2} = 562 \frac{BTU}{ft^2\text{-day}}$$

$$S = 562 \frac{BTU}{ft^2\text{-day}} \times 31 \text{ days} = 17{,}422 \frac{BTU}{ft^2\text{-January}}$$

To derive L use the degree day method (see page 85). In Great Falls the heating load for an indoor temperature 65°F and an outdoor design temperature of −15°F (see page 84) will be 37,065 $\frac{\text{BTU}}{\text{HR}}$

Then the heat required per degree day can be computed:

$$\frac{37{,}065\ \frac{\text{BTU}}{\text{HR}}}{(65-(-15))°\text{F}} \times 24\ \frac{\text{HR}}{\text{day}} = 11{,}119\ \frac{\text{BTU}}{\text{DD}}$$

Since there are 1349 DD in January

$$S = 11{,}119\ \frac{\text{BTU}}{\text{DD}} \times 1349\ \text{DD} = 15{,}000{,}000\ \text{BTU}$$

Therefore,

$$\frac{SA}{L} = \frac{17{,}422\ \frac{\text{BTU}}{\text{ft}^2\text{-Jan.}} \times 600\ \text{ft}^2}{15{,}000{,}000\ \frac{\text{BTU}}{\text{Jan}}}$$

$$\frac{SA}{L} = 0.70$$

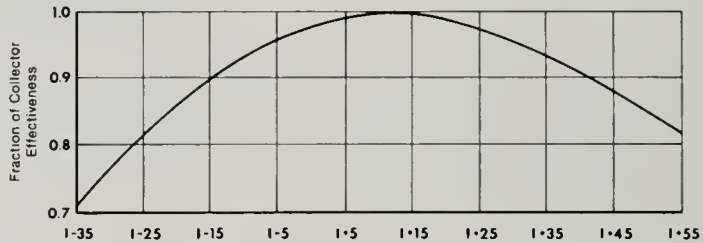
from the f-chart, when $\frac{SA}{L} = 0.70$, then f = 0.76

The air system will provide about 76 percent of the annual heating load. However, the efficiency of the system will also be affected by the slope and orientation of the collector.

To continue the above example: assume the collectors are mounted vertically and oriented 30° east of due south rather than optimally at 62° and due south. To determine the effect of this sub-optimal slope and orientation on collector efficiency first subtract the latitude (l) of Great Falls (47°) from the slope of the collector (90°) which equals 43°. Referring to Figure D-2 locate 1 + 43°, then read up the graph to the curve to determine the fraction of collector effectiveness at 1 + 43. That fraction is roughly .89. Then f = (0.76)(.89) = .68. Similarly, to find the effect of collector orientation on collector effectiveness read up from 30° east of south on Figure D-3. The fractional reduction of collector efficiency when the collector is oriented 30° east of south is .95. Then f = 0.76 (.95) = .64.

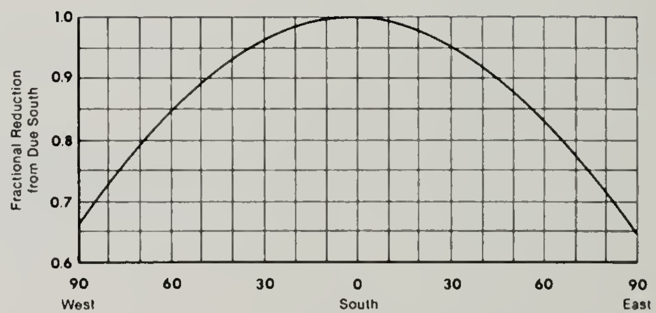
The combined effect of a 90° slope and 30° east of due south orientation is to reduce the contribution of the solar system to the home's annual heating load from 76 percent to 66 percent (.68 + .64/2 = .66).

Figure D-2. Effect of Collector Slope (from horizontal) on Collector Effectiveness



Source. Mechanical Engineering Department, Montana State University, Bozeman, Montana, 1978

Figure D-3. Effect of Collector Orientation (from due south) on Collector Effectiveness



Source Mechanical Engineering Department, Montana State University, Bozeman, Montana, 1978

APPENDIX E
THE SKYLINE CHART

A basic understanding of the sun's position in relation to a building and site is necessary in order to effectively position either an active or passive solar system. The following charts and explanation from the **Passive Solar Energy Book** by Edward Mazria will serve as a guide to plotting the position of the sun in relation to a solar site.

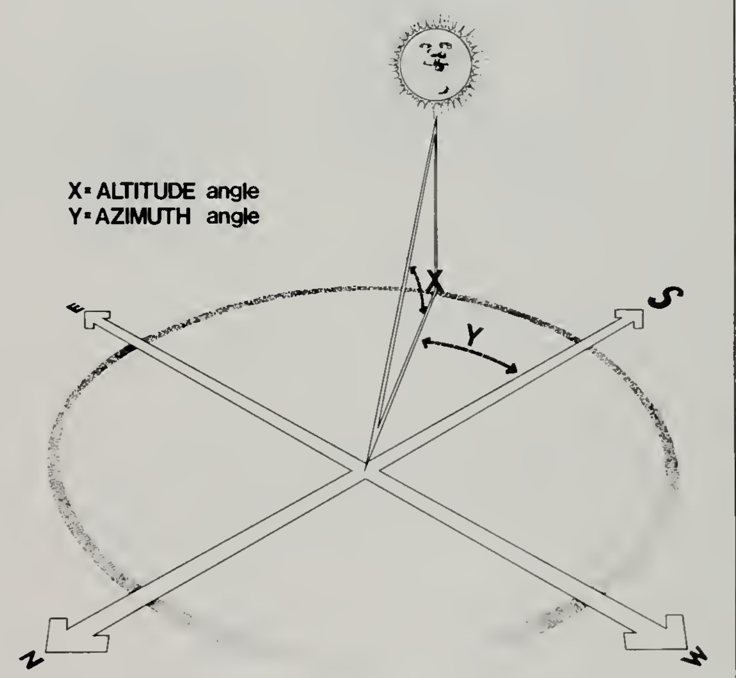
The Cylindrical Sun Chart

The ''Cylindrical Sun Chart,'' which is developed here, provides an easy-to-understand and convenient way to predict the sun's movement across the sky as seen from any point in the world between 28° and 56°NL. The chart is a vertical projection of the sun's path as seen from earth. It could be said, then, that the Sun Chart is an earth-based view of the sun's movement across the skydome.

The following sequence is a description of how a sun chart is developed. It is included here to provide you with a visual understanding of the sun's movement across the skydome.

Two coordinates are needed to locate the position of the sun in the sky. They are called the altitude and azimuth (also called the bearing angle).

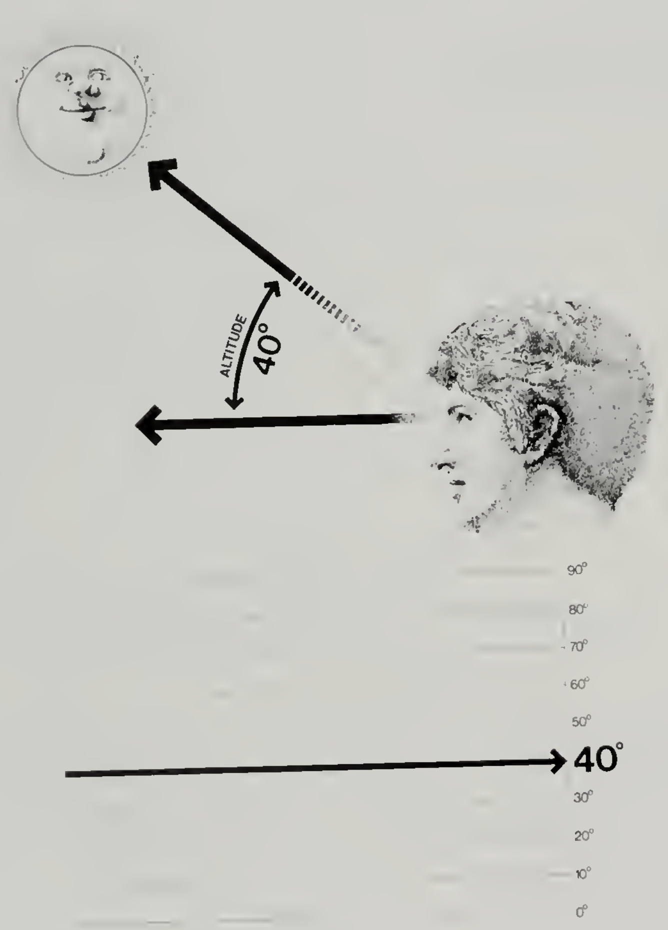
Figure E-1. Altitude and Azimuth Angles



Altitude

Solar altitude is the angle measured between the horizon and the position of the sun above the horizon. The horizontal lines on the chart represent altitude angles in 10° increments above the horizon.

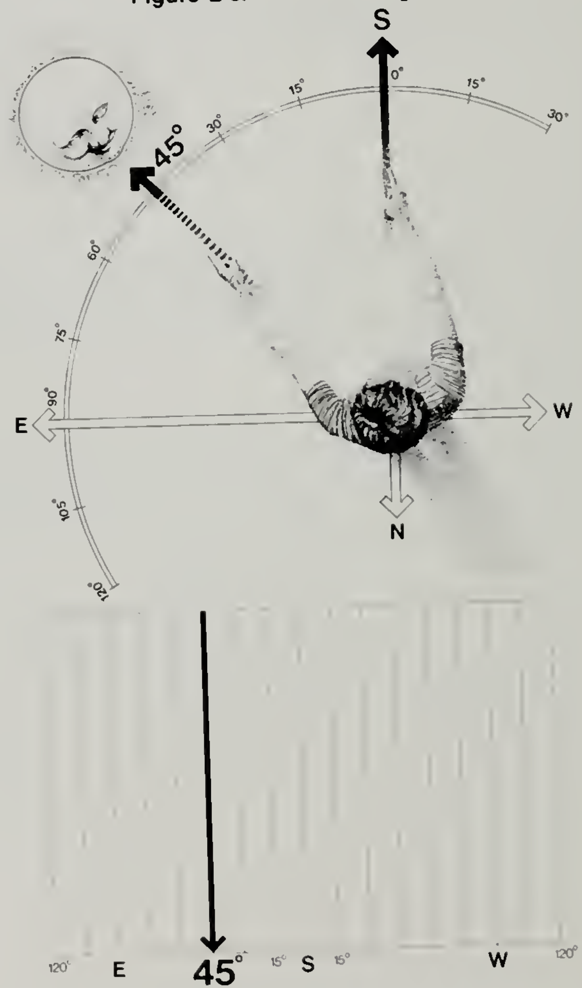
Figure E-2. Altitude Angle



Azimuth (bearing angle)

Solar azimuth is the angle along the horizon of the position of the sun, measured to the east or west of true south.

Figure E-3. Azimuth Angle

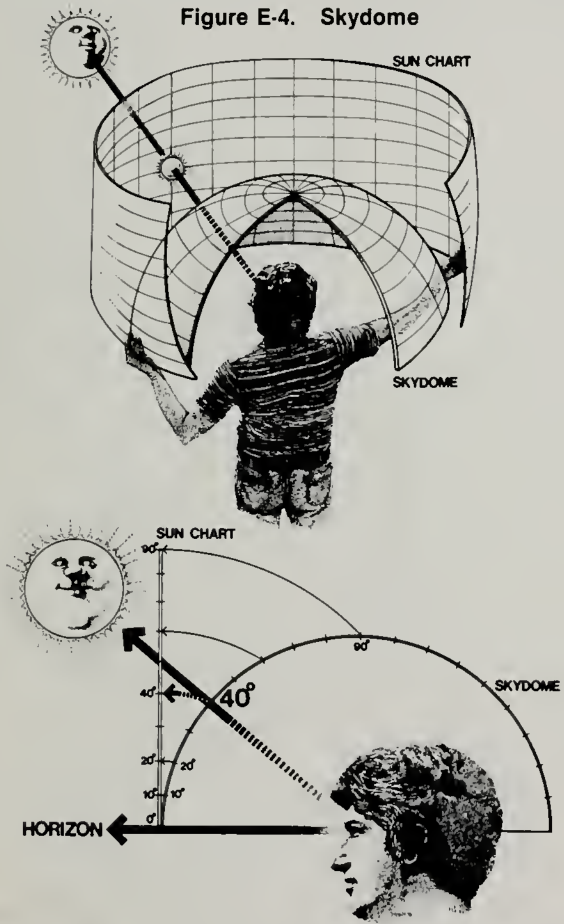


Skydome (sky vault)

The skydome is the visible hemisphere of sky, above the horizon, in all directions. The grid on the chart represents the vertical and horizontal angles of the whole skydome. It is as if there were a clear dome around the observer, and then the chart were peeled off of this dome,* stretched out and laid flat.

*In reality this is not possible. The intention of the illustration is to present you with a visual image of the skydome projected onto a flat sheet.

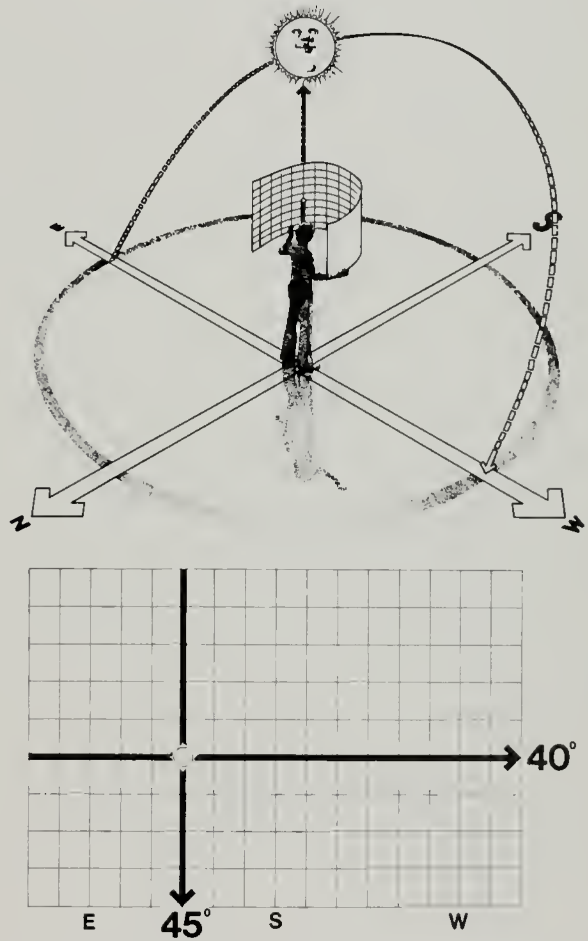
Figure E-4. Skydome



Sun's Position

Once the altitude and azimuth angles are known, the sun can be located at any position in the sky.

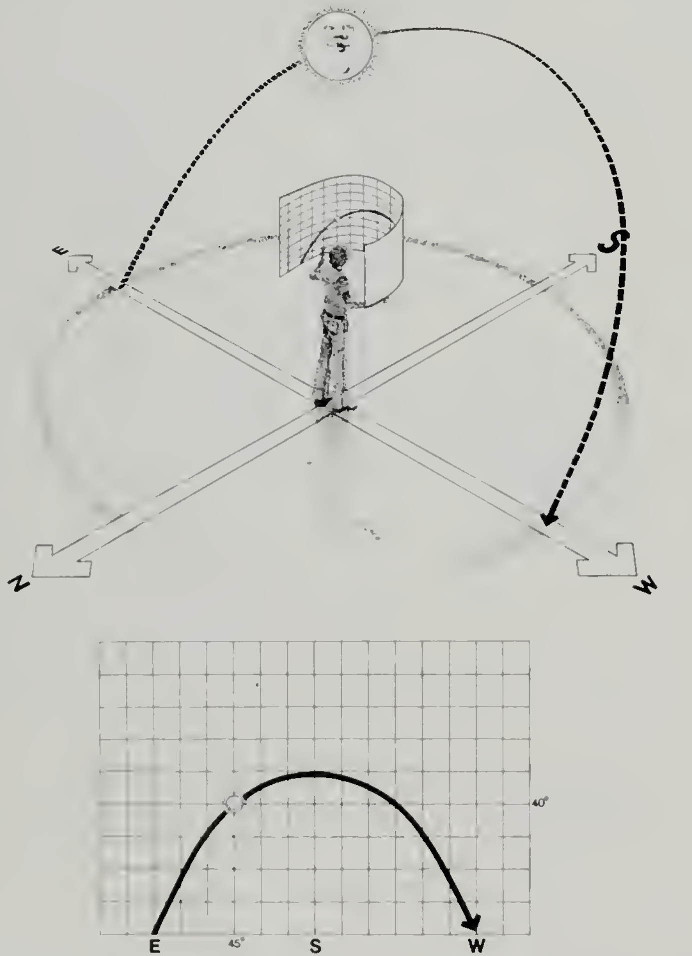
Figure E-5. Sun's Position



Sun's Path

By connecting the points of the location of the sun, at different times throughout the day, the sun's path for that day can be drawn.

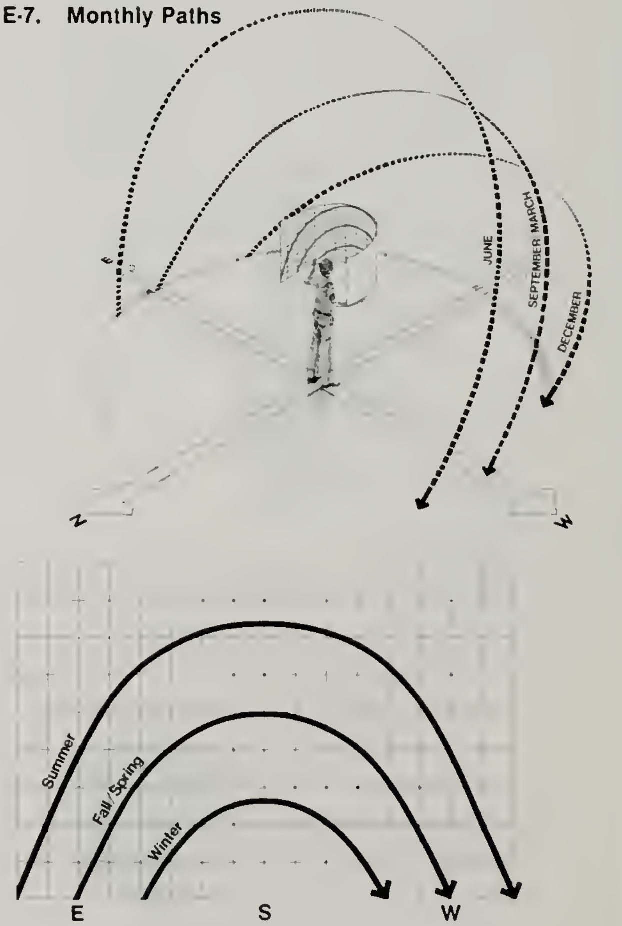
Figure E-6. Sun's Path



Monthly Paths

Thus, we can plot the sun's path for any day of the year. The lines shown represent the sun's path for the twentieth day of each month. The sun's path is longest during the summer months when it reaches its highest altitude, rising and setting with the widest azimuth angle from true south. During the winter months the sun is much lower in the sky, rising and setting with the narrowest azimuth angles from true south.

Figure E-7. Monthly Paths



Times of Day

Finally, if we connect the times of day on each sun path we get a heavy dotted line which represents the hours of the day. This completes the Cylindrical Sun Chart.

Figure E-8. Times of Day

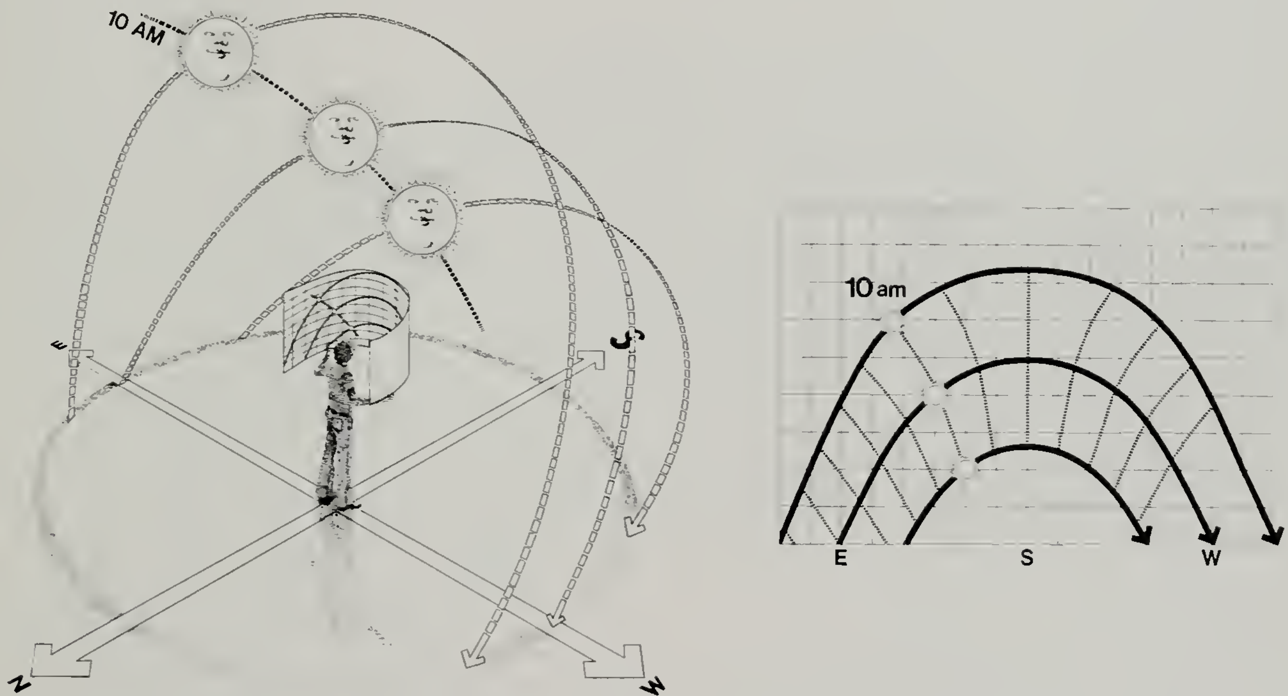


Figure E-9. Sun Chart for 44° N Latitude

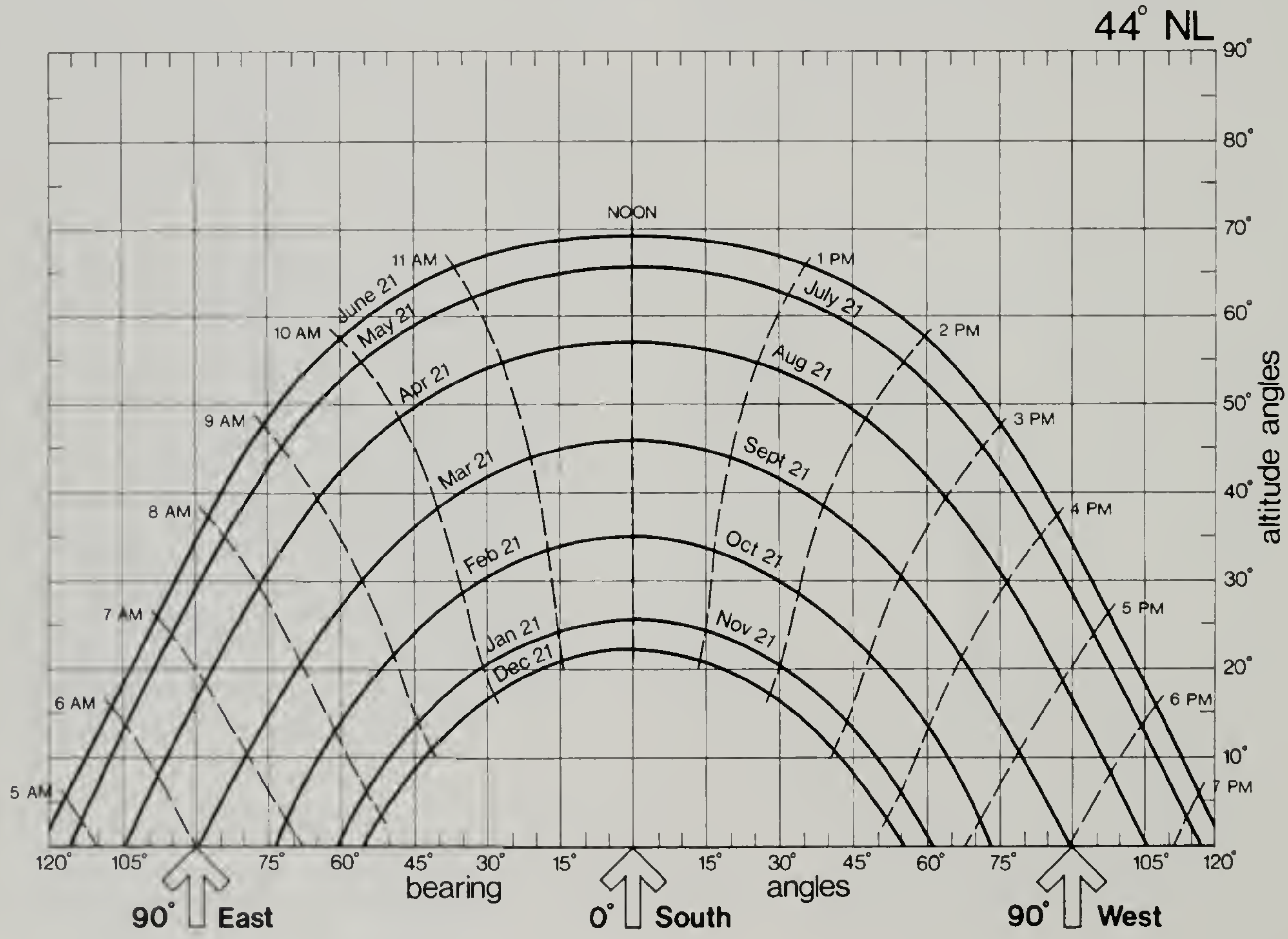
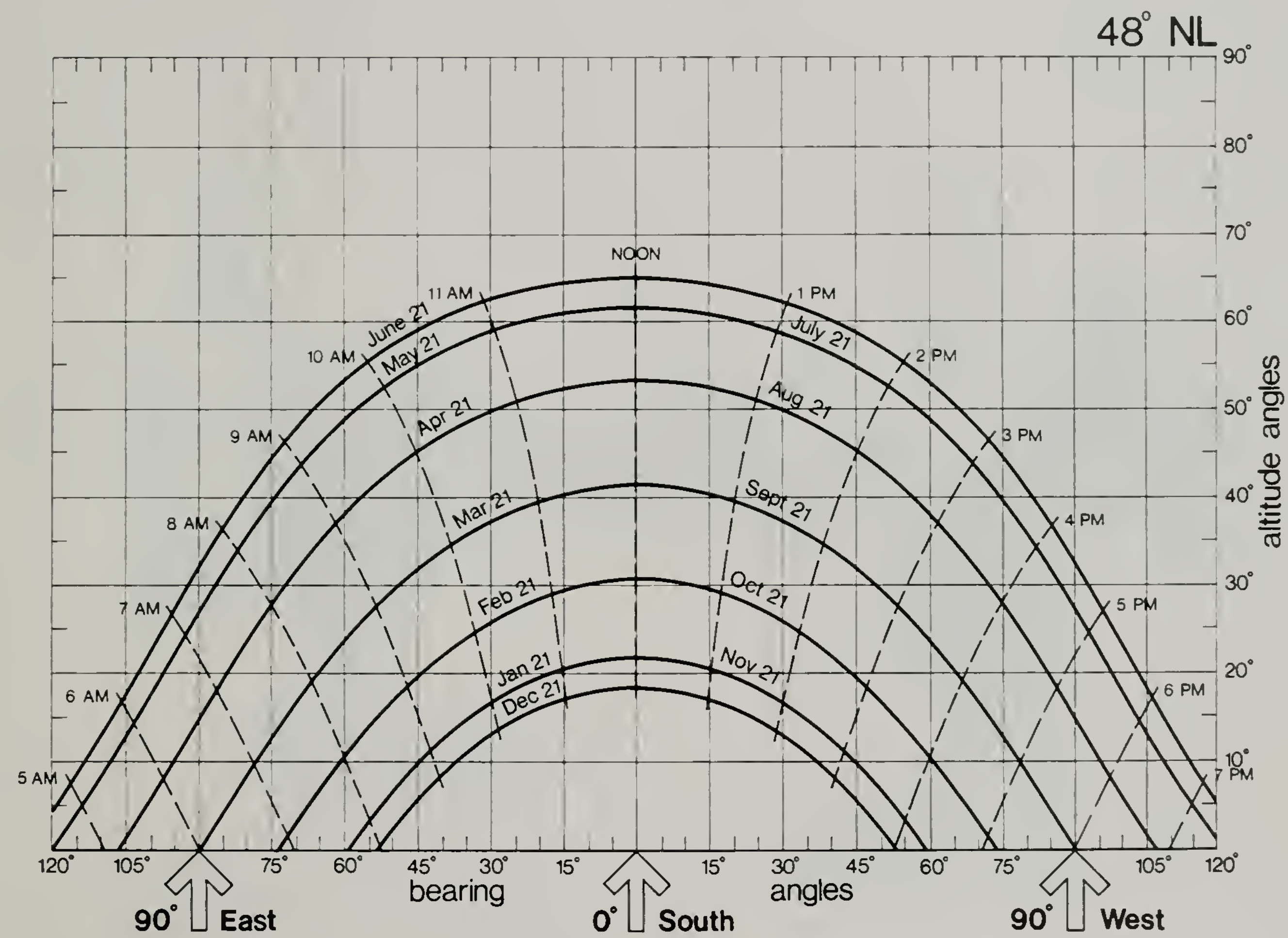


Figure E-10. Sun Chart for 48° N Latitude



Plotting the Skyline

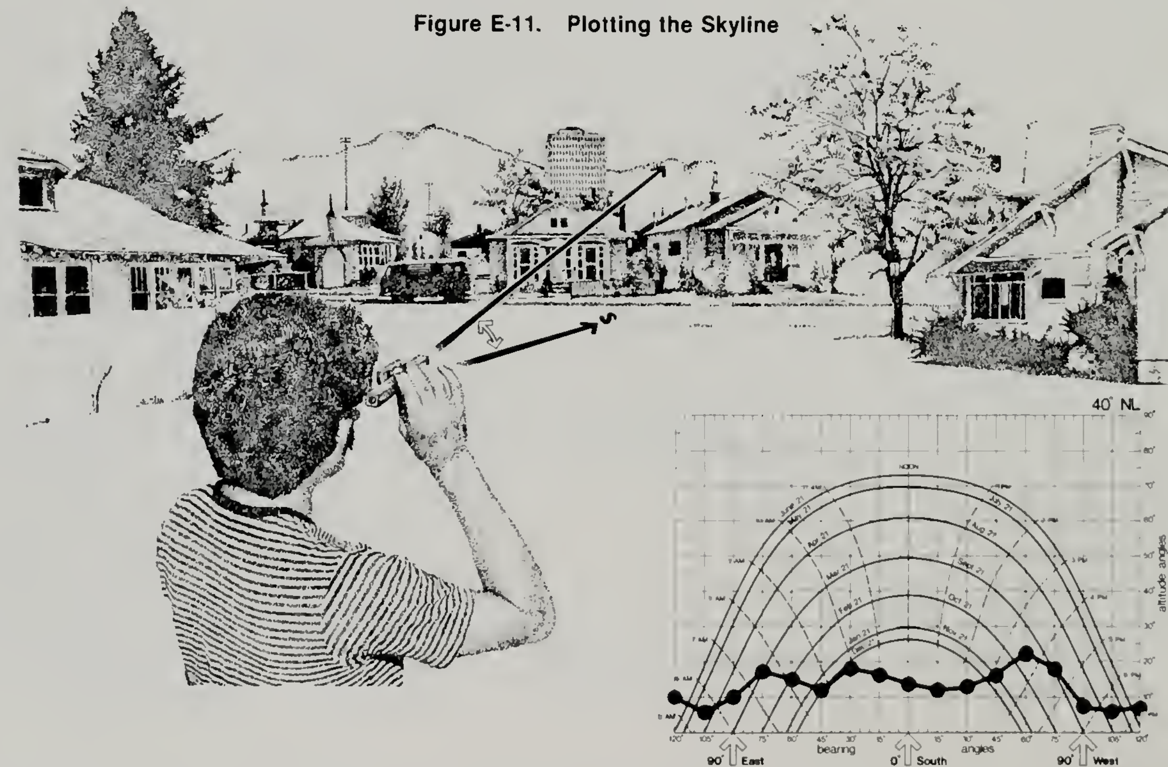
To accurately determine the times that direct sun is blocked from reaching any point on a site it is necessary to plot the obstructions as seen from that point. This is done by plotting the "skyline" directly on the sun chart. If the skyline to the south is low with no obstructions such as tall trees, buildings or abruptly rising hills, the following procedure is unnecessary as all points on the site will receive sun during the winter.

To plot the skyline, you will need either a transit or a compass (to find the azimuth angles of the skyline), an abney (to find the altitude angle of the skyline), and a copy of the sun chart for your location.

Next, place yourself at the approximate location on the site where you want to put the building. Plot the skyline (from that point) on the sun chart as follows:

1. Use the compass or transit, to determine which direction is true south (remember magnetic variation).
2. Aim the abney or transit true south to determine the altitude (angle above the horizon) of the skyline. Plot this point on the sun chart above the azimuth angle 0° (true south).
3. Similarly, determine and record the altitude angle of the skyline for each 15° (azimuth angle) along the horizon, both to the east and west of south, to at least 120°. This is a total of 17 altitude readings. Plot these readings above their respective azimuth angles on the sun chart and connect them with a line.

Figure E-11. Plotting the Skyline

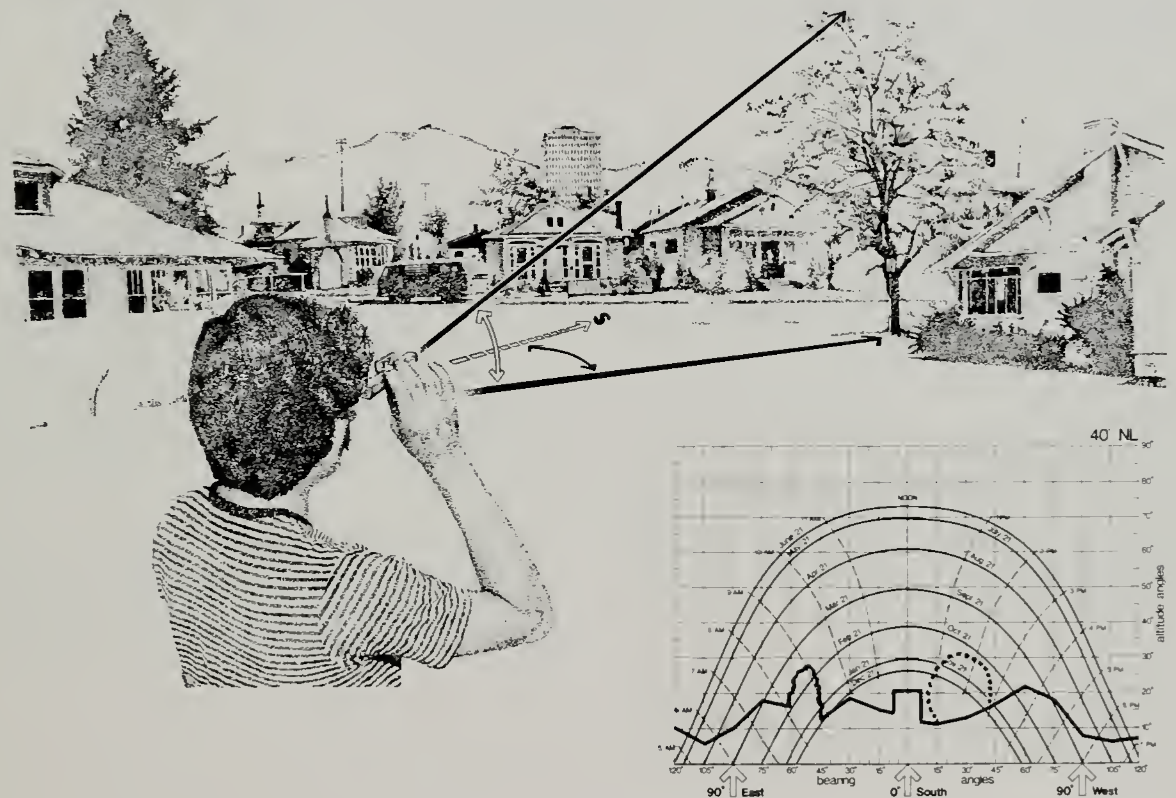


4. Find both the azimuth and altitude angles for isolated tall objects that block the sun during the winter, such as tall evergreen trees, and plot them on the chart.

5. Finally, plot the deciduous trees in the skyline with a dotted line. These are of special nature, because by losing their leaves in the winter they let most of the sun pass through as long as they are not densely spaced.

This completes the skyline. The open areas on the sun chart are the times when the sun will reach that point on the site.

Figure E-12. Plotting Tall Permanent Objects



APPENDIX F
FINANCING RENEWABLE ENERGY SYSTEMS

Federal Tax Credits

The National Energy Act passed in late 1978 provides tax credits for conservation measures and renewable energy systems.

A non-refundable credit—up to $300—is provided for 15 percent of the first $2,000 invested in qualifying equipment. The property claimed for the credit must be installed between April 20, 1977 and December 31, 1985 in a principal residence already in existence on April 20, 1977. Condominiums and cooperatives are included in the credit if used as a principal residence; vacation homes are not. A credit is provided for investments in insulation, caulking, weather-stripping, modified flue openings, storm or thermal doors and windows, automatic furnace ignition systems, clock thermostats, and other items.

A non-refundable credit for investments in solar, wind, and other renewable sources of energy is available for both new and existing residences. The credit would be 30 percent of the first $2,000 and 20 percent of the next $8,000 spent, for a maximum of $2,200. Any investment from April 20, 1977 through December 31, 1985 will be eligible if the equipment is used to heat or cool a home or provide hot water.

Federal Grants

For information about current and upcoming grant programs for solar energy use by homeowners and individuals contact:

Solar Heating and Cooling Information Center
Box 16-7
Rockville, Maryland 20850
Toll-free 800-523-2929

State Tax Deductions and Credits

The State of Montana allows a tax deduction for investment in energy conservation and a tax credit for non-fossil energy systems. The following explain these allowances.

Montana Tax Credit For Non-Fossil Energy Systems

Who Is Eligible?

- any individual resident who completes installation of an energy system using a recognized non-fossil* form of energy generation in his or her dwelling prior to December 31, 1982
- any individual resident who acquires the title to a dwelling equipped with a recognized energy system whose credit has not yet been claimed
- to be eligible for this credit, individuals must be paying state income tax

Main Features of the Program

- amount of credit: 10% - $1.00 to $1000
  5% - $1001 to $4000 (including installation costs)
- maximum allowable credit is $250
- credit is to be deducted from taxpayer's income liability for the taxable year in which the energy system was acquired
- if the credit exceeds the taxpayer's income tax liability for the taxable year it may be carried over for deduction the next succeeding taxable year or years (up to 4 years)
- individuals must itemize tax returns
- program begins January 1, 1977 and ends on December 31, 1982
- if the federal government institutes a similar program, check with the Montana Department of Revenue for adjustments in the credit schedule
- all credits are subject to the approval of the Montana Department of Revenue

Steps for Claiming Credit

- keep copies of all receipts for costs of installation (labor) and purchased materials
- claim credit on Montana state income tax form
- consult the Montana Department of Revenue for further information

*Non-Fossil is defined as (1) any system which captures or converts useful energy from solar heat, wind, solid waste or the decomposition of organic wastes; (2) any system producing electric power from solid wood waste; or (3) any system for the utilization of water power by means of an impoundment of water not over 20 acres in surface area.

Source: National Center for Appropriate Technology, Butte, Montana, 1978.

Montana Tax Deduction for Investment in Energy Conservation

Who Is Eligible?

- any individual making a capital investment which increases the energy efficiency of a building
- any individual building a new structure wanting to weatherize it over standards on original plans
- to be eligible for this deduction, individuals must be paying state income tax

Main Features of the Program

- amount of deduction:

(1) Residential	(2) Non-Residential/Commercial
100% - $1.00 to $1000	100% - $1.00 to $2000
50% - $1001 to $2000	50% - $2001 to $4000
20% - $2001 to $3000	20% - $4001 to $6000
10% - $3001 to $4000	10% - $6001 to $8000

- claims may be made for expenditures and capital investments which are not financed by state, federal or private grants for energy conservation
- deduction applies to existing buildings lacking sufficient insulation, storm windows and other energy-conserving features
- deduction also applies to new buildings that are being weatherized beyond accepted standards (to be adopted by the Montana Department of Revenue)
- in addition, deduction can apply to such items as: clock thermostats, storm windows, water flow restrictors, mixing valves for hot water supplies, and all accepted energy saving measures by the Montana Department of Revenue
- there is no carryover of deduction to the next taxable year if deduction exceeds taxable liability
- individuals must itemize tax returns
- all deductions are subject to approval by the Montana Department of Revenue

Steps for Calculating Deduction

- keep copies of all receipts for costs of installation (labor) and purchased materials
- claim deduction on Montana state income tax form
- consult the Montana Department of Revenue for further information

Source National Center for Appropriate Technology, Butte, Montana, 1978

APPENDIX G

TEST CELL RESULTS FOR DIRECT AND THERMAL STORAGE WALL DESIGNS

NCAT has recently published preliminary results of the effectiveness of direct gain and trombe wall models which are called cells. NCAT recorded data on the models from February 21 through March 2, 1978. The conclusions are provisional until further testing has been conducted.

The trombe cell and the direct gain cell each have interior dimensions of 10.2 feet high, 5.2 feet wide, and 7.3 feet deep. The glazing on each model is 35.5 ft^2 and the concrete block floor is 3.6 inches thick. Both cells have high density concrete blocks (132 lb/ft^3) for thermal storage; in addition, the walls of the direct gain cell are lined with concrete blocks 7.6 inches thick. The trombe wall is 15.6 inches thick, 9.5 feet high and is placed 6 inches from the inner glazing layer. Its exterior surface is painted black and it does not have bottom vents. However, since the wall does not extend to the ceiling, there is a convective flow of warm air to the interior of the cell. The absence of vents at the bottom of the wall prevents reverse flow at night.

During the period of measurement, both cell models performed well, with interior air temperatures averaging 64.4-68 degrees F and remaining above 50 degrees F even when the ambient (outside) air temperature dropped below −13 degrees F. The direct gain air and storage surface temperatures consistently were 1.8 - 3.6 degrees F higher than the air and interior wall surface temperature of the trombe cell. However, the trombe cell air temperatures showed less variation over the 10 day period with the difference between daily maxima and minima averaging approximately 9 degrees F for the trombe cell and 11.7 degrees F for the direct gain.

The interior surface temperature of the trombe wall lagged the solar pulse by about 12 hours; i.e., it reached its maximum shortly before midnight and its minimum shortly before noon. However, the interior air temperature of the cell was raised by both the convective flow of warm air from the heated surface of the trombe wall and some penetration of radiation through the 8.4 inch opening between the top of the trombe wall and the test cell ceiling. Thus, the opening above the wall resulted in the interior air temperature being greater during the day than it would have been if heat transfer had occurred only through the wall.

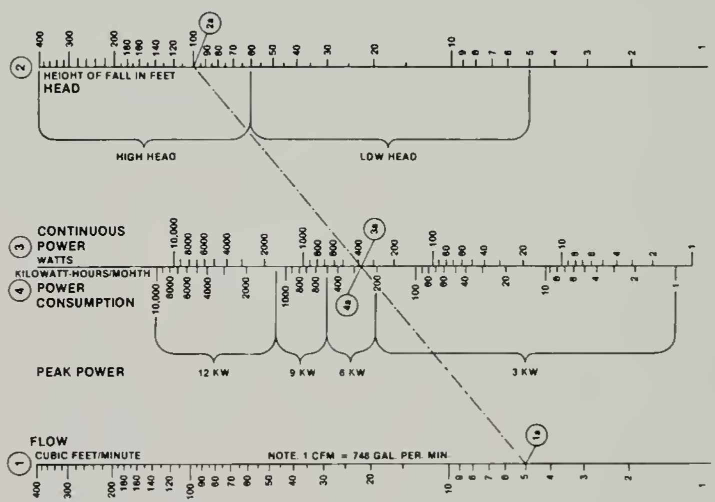
APPENDIX H
CALCULATING POWER OUTPUT FOR IMPULSE TURBINES

Once head and flow have been determined, the amount of power can be calculated through the use of a nomograph (Figure H-1).

How to use the nomograph:

1. Locate flow value on scale 1.
2. Locate head value on scale 2.
3. Using a straight edge (ruler), draw a straight line through these two values. (See the example on the nomograph using 5 C.F.M. flow 1a, and 100 ft. of head 2a.)
4. Continuous power output appears when the line intersects scale 3. (From the example, the value is about 360 watts 3a.)
5. Scale 4 gives the equivalent total power consumption per month in KW hr/mo that may be expected. (From the example, 360 watts 3a continuous output will produce 260 KW hr/mo 4a, of usable electricity.)
6. The peak power output of the system is shown by the brackets. (From the example, the value is 6 KW.)

Figure H-1. Hydroelectric Power Conversion Nomograph



Source. Bill Delp, Independent Power Developers, Sandpoint, Idaho.

APPENDIX I

POTENTIAL ENVIRONMENTAL IMPACTS OF RENEWABLE ENERGY SYSTEMS

Reliable, quantitative information about the environmental impacts of renewable energy systems is lacking because of limited field experience with most of these systems. However, potential environmental impacts of solar, wind, hydro, biomass and geothermal energy systems can be identified. The following tables identify the potential impacts of these systems. The source for these tables is **Environmental Data for Energy Technology: Policy Analysis** by the Mitre Corporation (McLean, Virginia, 1979) for the U.S. Department of Energy.

Table I-1.
Potential Impacts of Active Flat Plate Collectors Systems

- Resources used during fabrication and manufacture of collectors—aluminum, copper, glass.
- Health and safety hazards to workers engaged in the manufacture and installation of system components.
- Collector working fluids, such as ethylene glycol, are toxic. Normally, this working fluid poses no hazard. However, flushing the collector fluids can result in accidental spills. In the event of collector overheating and fire, the working fluids may release nitrogen oxides, carbon monoxide and particulates.
- Other air pollutants, in the event of collector overheating and fire, are volatile organic compounds from the insulation as well as gaseous emissions from degraded plastics and synthetics.
- Land use when siting collectors separately.

Table I-2.
Potential Impacts of Passive Solar Systems

- Resources used during construction of passive system—glass, concrete.

Table I-3.
Potential Impacts of Anaerobic Digestion

- Disposal of digester sludge.
- Hydrogen sulfide emissions.

Table I-4.
Potential Impacts of Wood Collection

- Air pollution generated by trucks and other collection equipment—fugitive dust, sulfur dioxide, nitrous oxide, hydrocarbons and carbon monoxide.
- Soil erosion and silt-laden runoff
- Loss of soil nutrients (nitrogen, phosphorous and potassium) due to residue removal.
- Intermittent noise during operation of vehicles and associated machinery.

Table I-5.
Potential Impacts of Wind Energy Conversion Systems

- Tower collapse and blade throw could result in property damage and bodily harm.
- Airplane hazard.
- Bird and insect collisions with wind system.
- Interference with electromagnetic radiation at ultrahigh frequencies.
- Visual pollution.

Table I-6.
Potential Impacts of Small Scale Hydro Systems

- Dam safety and potential effects of dam failure.
- Releases of impounded chemicals.
- Conflicts of land and water use.
- Effects on aquatic and semiaquatic organisms.
- Water quality and quantity may be altered up and down stream with potential changes in dissolved gases, temperature, and water levels.

Table I-7.
Potential Impacts of Geothermal Systems

- Release of gases—hydrogen sulfide, ammonia, methane, carbon dioxide, boron hydrogen, nitrogen and argon.
- Release of arsenic and mercury into atmosphere.
- Groundwater contamination—carbonates, ammonia, sulfur dioxide, sulfate, sulfur, nitrate, chloride, calcium, magnesium, silicon, boron.
- High noise levels during well construction, plant construction and plant operation.
- Alteration of runoff patterns.
- Wildlife habitat disruption.
- Increased seismic activity.
- Release of radioactive radon 222 into air.

GLOSSARY

Absorber
the blackened surface in a solar collector that absorbs the solar radiation and converts it to heat energy.

Ambient temperature
outside air temperature.

Anaerobic digestion
the decay of organic material in the absence of oxygen.

Altitude
the angular distance from the horizon to the sun.

Aquifer
underground reservoir of water.

Auxiliary heat
the extra heat provided by a conventional heating system for periods of cloudiness or intense cold, when a solar heating system cannot provide enough.

Average power load
the normal electrical demand.

Azimuth
the angular distance between true south and the point on the horizon directly below the sun.

Bio-gas
one of the products of anaerobic digestion; bio-gas, contains methane, carbon dioxide, nitrogen, and traces of other gases.

Bioconversion
utilization of agricultural or municipal wastes to provide fuel.

Biomass
any material of biological origin capable of bio-conversion.

BTU or British thermal unit
the quantity of heat needed to raise the temperature of 1 pound of water 1°F.

Collector efficiency
The fraction of incoming radiation captured by the collector. If the system captures half of the incoming radiation, then the system is 50 percent efficient. Efficiency is the capability of a collector to capture BTUs under various climatic conditions. Efficiency varies according to outside temperatures, whether skies are clear or cloudy, whether it is windy or not, and, of course, the quality of the collector. A collector cannot be 100 percent efficient; 55 percent is good under desirable weather conditions.

Combustion
the transformation of wood into heat, chemicals, and gases through chemical combination of hydrogen and carbon in the wood fuel with oxygen in the air.

Conduction
the transfer of heat energy through a material by the motion of adjacent atoms and molecules.

Convection
the transfer of heat energy from one location to another by the motion of fluids that carry the heat.

Degree-Day
a unit that represents a 1°F deviation from some fixed reference point (usually 65°F) in the mean daily outdoor temperature. If the outdoor temperature is 40°F for one day, then 25 (65° minus 40°) Degree Days result. Used to determine the demand of a heating season for different locales.

Design heat load
the total heat loss from a house under the most severe winter conditions likely to occur.

Design temperature
a temperature close to the lowest expected for a location, used to determine the design heat load.

Diffuse radiation
sunlight that is scattered from air molecules, dust, and water vapor and comes from the entire sky vault.

Direct radiation
solar radiation that comes straight from the sun, casting shadows on a clear day.

Eutectic salts
a group of materials that melt at low temperatures, absorbing large quantities of heat and then, as they re-crystallize, release that heat. One method used for storing solar energy as heat.

Gasohol
a blend of gasoline and ethyl alcohol.

Generating capacity
the greatest possible output in watts of an electrical generator (or alternator).

Head
the difference in elevation between two points on a stream and so a measure of the energy of the water.

Gravity convection
the natural movement of heat through a body of fluid that occurs when a warm fluid rises and cool fluid sinks under the influence of gravity.

Heat exchanger
a device, such as a coiled copper tube immersed in a tank of water, that is used to transfer heat from one fluid to another through an intervening metal surface.

Heating season
the period from about October 1 to about May 1, during which additional heat is needed to keep a house warm.

Heat storage
a device or medium that absorbs collected solar heat and stores it for periods of inclement or cold weather.

Infiltration
the movement of outdoor air into a building through cracks around windows and doors or in walls, roofs, and floors.

Insolation
the total amount of solar radiation—direct, diffuse and reflected—striking a surface exposed to the sky.

Insulation
a material with high resistance or R-value that is used to retard heat flow.

Kilowatt
one thousand watts of power; equal to about 1⅓ horsepower.

Kiliowatt-Hour (kWh)
The amount of energy equivalent to 1 kilowatt of power being used for 1 hour = 3,413 BTU.

Langley
a unit of measurement of insolation. (One langley equals one gram calorie per square centimeter.) The langley was named for American astronomer Samuel P. Langley.

Life-cycle costing
an estimating method in which the long-term costs such as energy consumption, maintenance, and repair can be included in the comparison of several system alternatives.

Natural convection
see gravity convection.

Peak power load
the greatest possible electrical demand.

Thermal resistance
a measure of the ability of a substance to resist the flow of heat. Insulation products are typically characterized by their R values. Thus, a specification of R-11 means that insulation displays 11 resistance units. The higher the R value, the better the insulating ability. R is a simple common denominator for describing all types of insulation and all kinds of dwelling construction. For example, all insulation rated R-11 has the same insulation ability no matter what its material or thickness.

Rated wind speed
the wind speed at which a wind energy conversion system is producing 100 percent of the rated capacity of the alternator.

Retrofitting
the application of a solar heating or cooling system to an existing building.

Solar constant
the average amount of solar radiation reaching the earth's atmosphere per minute. This is just under 2 langleys, or 2 gram calories per square centimeter. This is equivalent to 442.4 BTU/hr/ft, 1395 watts/m or .1395 watts/cm.

Solar radiation
electromagnetic radiation emitted by the sun.

Sun tracking
following the sun with a solar collector to make the collector more effective.

System efficiency
BTU's are lost from the time the sun's rays hit the collector to the moment they are used to heat the house or the water supply. The ratio of delivered BTUs to BTUs received by the collector is the system efficiency.

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